VEÐURSTOFA ÍSLANDS

Report
02004

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Application of practical experience gained from two recent large earthquakes in the South Iceland seismic zone in the context of earthquake prediction research to develop technology for improving preparedness and mitigating risk – PREPARED

An EC proposal

VÍ-JA01
Reykjavík
January 2002

B1 Title page

Application of practical experience gained from two recent large earthquakes in the South Iceland seismic zome in the context of earthquake prediction research to develop technology for improving preparedness and mitigating risk

PREPARED

Energy, Environment and Sustainable Development

Part A: Environment and Sustainable Development

October 11, 2001

B2 Contents

B3 Objectives

Context

Two magnitude Ms=6.6 earthquakes rocked the inhabitants of the South Iceland seismic zone (SISZ) in June 2000 for the first time, so severely, in almost a century. Previous to the 2000 events, the last sequence of six such large earthquakes in this zone occurred in the period 1896-1912. Their magnitude reached 7, as recorded instrumentally for the 1912 earthquake.

Historically, earthquakes in this area have been catastrophic, striking fear in the community. This time, the likelihood of imminent renewed seismic activity led to several actions of preparedness including multipurpose real-time monitoring of the area. Scientific researchers undertook hazard assessments to prepare for stronger building codes, as well as trying to understand the dynamics:

The SIL-project, "Earthquake prediction research in the South Iceland lowland" (1988-1995), was a common project of the Nordic European countries. Its main achievement was to develop and install the SIL seismological measurement system around the SISZ, revealing detailed information about crustal conditions and crustal processes based on microearthquakes.

The PRENLAB-projects, "Earthquake prediction research in a natural laboratory". These were European Commission seismic risk projects, PRENLAB and PRENLAB-2, carried out in 1996-2000. These were multidisciplinary research projects aiming at better understanding of processes leading to large earthquakes and their effects.

Other time series of monitoring were intensified because increased exepectations for large earthquakes in the SISZ. Repeated GPS measurements began in the area before 1990, becoming continuous in 1998. Volumetric borehole strainmeter measurements started in the SISZ in 1979. Time series of radon exist from 1977 to 1993 and since 1999. A network of strong-motion seismometers recorded the earthquakes in 2000. Renewed geological studies revealed faults and soil structure.

A unique dataset. These activities collected a unique dataset. For the year 2000 earthquakes, it reveals premonitory process, nucleation, fault process and co-seismic effects as well as long-lasting and wide-spread triggered activity. Studying these data provides an opportunity to understand the crustal processes involved in and preceding earthquake release and basis for warnings.

Successful and useful warnings

Because of these preparatory research actions, the scientists, the public and the housebuilders were relatively well prepared for these earthquakes and no lives were lost.

The useful short-term warning that could be issued before the second large earthquake as well as the ongoing long-term warnings, launched the concept of a seismological early warning and information system (EWIS) in Iceland. The goal is to assimilate -

in real-time - all available observations and scientific knowledge to inform civil decision-makers sufficiently in advance or soon after to mitigate hazard.

General objective

The overall objective of the PREPARED project is to develop the technology and understanding needed for warning where, when, and how large earthquakes will strike. Each of these three to a degree which is possible. At all stages, the data collected for the 2000 events will be used to test and validate our results.

To meet this objective, we will build on the unique data collected and scientific results achieved during previous projects.

Iceland is a natural laboratory. With its fast and variable crustal processes, as well as high level technology in monitoring them, Iceland is the ideal test area for the project.

The PREPARED proposal will continue the successful PRENLAB and PRENLAB-2 projects. The basic methodology and the warning algorithms developed in these projects will be tested and developed further based on data from the June 2000 earthquakes. The project will also benefit from the experience gained in two ongoing EC projects: SMSITES, a multidisciplinary infrastructure project monitoring the Húsavík fault of North Iceland, and the ongoing RETINA project, EC natural hazards project, studying the interaction of natural hazards in the Azores, in the Alps, and in the Hengill area in Iceland.

What we aim to achieve. The role of earth sciences in mitigating seismic risk is manifold. We try to provide (time independent) probabilistic hazard assessment, time dependent hazard assessment, short-term warnings and early warnings or “nowcasting”. The basic purpose of all these information or warnings is to assess as well as possible the exact location, and surface effects of the impending earthquake.

Improving probabilistic hazard assessment. By precise mapping of numerous activated faults, by various observed surface effects and by modelling with earth realistic parameters we will make the hazard assessment more detailed as concerns the place and effects. This involves to forecast ground motion for preventive actions and engineering application. The results of the EC “Strong Ground Motion Estimates” project (ENV4-CT96-0296) can also contribute significantly here, besides the Icelandic experience.

Time-dependent hazard assessments and warnings. Earthquake prediction informing with useful precision about all aspects of an impending earthquake is hardly on the agenda. Based on our experience, however it is possible in many cases to provide useful information at different times in advance about some aspects of a probably impending earthquake. Judging from experience and availability of tools in Iceland, we think that such warnings can be based on seismological and hydrological data, radon anomalies, strain/deformation observations, as well as earth realistic models of crustal behavior and processes.

We classify our earthquake warnings and time-dependent hazard assessments into several scenarios:

Years/month in advance. Useful for concentration of various risk mitigating efforts, finding baseline, increasing research, increasing monitoring and strengthening of structures.

Weeks/days in advance. Useful for activating the civil protection and rescue groups, increased earth observations, and raising preparedness of people.

Hours/minutes in advance. Everyone involved begins preparing immediately for a hazardous event will occur anytime within a short-time. Such an alarm must have time limit; it must end sometime.

The earthquake occurs. Early warning, now-casting, real-time damage assessment. Usefulness: Assessment based on earlier knowledge as well as from observations of the earthquake used to help people and authorities, civil defence and rescue groups to mitigate the impact on people and society.

Post-quake information. To explain the hazardous event and try to assess and warn of further coupled hazards.

The aim of the project is to apply the available knowledge and results of earlier research and the new data acquired to enhance the information and warnings given at all these stages.

The various work packages of the project will aim at concrete results to enhance general hazard assessments, time dependent hazard assessments, short-term warnings and nowcasting (early information) for an impending earthquake. Although this is in first hand valid for mitigating risk in Iceland, the multidisciplinary and physical approach makes the results applicable at many other earthquake prone regions of the world.

B4 Contribution to programme/key action objectives

Contribution to EESD programme, 7.1 - The fight against major natural and technological hazards

The basic concept of the PREPARED proposal is generally the same as the objectives of EESD programme 7.1, that is, as it says in the EESD programme "through a better understanding of processes, mechanisms and events generating natural and technological hazards, to develop methods and technologies (including earth observations) for environmental/socio-economic impact and risk assessment, and management, and disaster preparedness, hazard forecasting, monitoring, prevention, evaluation and mitigation". Input to help civil protection is the main goal of PREPARED. Integration with e-sciences techniques for fast distribution of knowledge and warnings is applied, especially in the related EWIS (Early warning and information system) also operated by the coordinator, and for the scientific cooperation.

On one hand PREPARED applies results of the earlier EC PRENLAB projects, which were basically analyzing crustal processes leading to large earthquakes.

On the other hand PREPARED provides knowledge and warning algorithms to the Early warning and information system (EWIS). And through EWIS communication, hazard assessments and warnings are channeled to cooperating scientists, civil protection and authorities.

EWIS is a warning system under fast development in Iceland, cost by Icelandic government and the Icelandic Science Foundation. It is operated by the coordinator of PREPARED, securing the end user, risk mitigating outcome of the research.

Contribution to EESD 7.1. – 1.1, Seismic risk

Following items of the programme are directly dealt with in the PREPARED working packages:
WP 5, 5.1, 5.2, 5.3, 5.4 and 5.5, deal directly with the following aspects of the programme:
"Identification and characterization of high seismic risk areas."
"Improved methods and technologies to estimate local ground motion variations due to site specific effects for engineering applications."

WP 2, 2.1, 2.2, 2.3, 2.4, 2.5, 3, 3.1 and 3.2 directly deal with
"Identification and analysis of factors which increase the level of natural hazards."
"Development of new and improved methodologies for: risk reduction or mitigation, disaster preparedness."

The workpackages within WP 4 and WP 6 integrate the varios outcome of all the other workpackages and provide them with models and parameters which are basic for the progress. They deal directly with “Development of technologies and models to observe, analyze and monitor earthquake related parameters and phenomena”.

"Common use of existing test site"; the "Iceland Natural Laboratory" test site is the background of all work in PREPARED.

The "end-user/stakeholder-driven, problem solving and policy relevant research" is the main basis for the coordinator, who is responsible for the early warning and information system (EWIS) and has warning responsibilities to the authorities and civil protection.

B5 Innovation

About the state-of-the-art in providing earthquake warnings

Hazard assessment in the classical sense provides, on the basis of earthquake catalogue data, information on the probability of earthquake occurrence and intensities in a seismic region. The usual assumption is that the earthquakes are independent of each other. The regions are large, on the order of tens of kilometers. Such a hazard assessment is the basis for risk assessment and building codes which has a legal status.

Time dependent hazard assessment is also estimated when information about general tectonics is introduced, claiming that a region can only hold a certain amount of strain energy, which is released in earthquakes, and then it will take time for the strain energy to build up again. Such an assessment is so coarse in space and time that it has mainly scientific interest, spurs scientific actions and general civil protection precautions.

Earthquake prediction research is in a state of development. Although we can by no means claim that it is possible to warn against all earthquakes, results of multidisciplinary earthquake prediction research are already providing answers which help to provide warnings about some aspects of impending earthquakes in some cases.

A good example of this is a very useful warning that was issued to the Iceland Civil Defence 25 hours before the second magnitude 6.6 earthquake in South Iceland struck, on June 21, 2000. In this warning the correct location was stated within a few kilometers, as well as the right fault orientation and magnitude for the earthquake. The warning urged the civil defence organizations to take all necessary preparatory measures for an earthquake that should be expected at any moment. [32].

There was no short-term warning before the first large earthquake of year 2000, i.e. on June 17. However, there was a general assessment, published in journals [30]; [29]; [33], about the probable location (and the fault direction) of the next expected large earthquake in the South Iceland seismic zone (SISZ). The June 17 earthquake occurred within the 10 km wide area of expected location (Stefánsson et al. 2000b; Stefánsson et al. 1993; Stefánsson and Halldórsson 1988).

In hindsight studies it was observed that even the first earthquake had small foreshocks lining up along the becoming fault [32] [33].

In fact all the larger earthquakes (M>4.5) in the last 10 years in Iceland have been preceded by small premonitory activity [31]; [34]; [28], indicating that in these earthquakes, related processes started before them. In 1998 a magnitude 5 earthquake was forecast to be imminent at the western end of the SISZ. The prediction, size and location, was made a few days ahead of the event, in real-time, on basis of shear-wave splitting, high nearby seismicity and general understanding of the tectonics of the area [8]. It is a request from society and from the scientific community to find ways to understand and make use of such possible premonitory effects for warnings, short- or long-term, if possible.

Since 1992 there has been an automatic seismic alert system operated by the coordinator, P1, in Iceland, with the purpose of activating seismologists in case of increased activity. Since the summer 2000, new algorithms have been added to this system, based on specified patterns in microearthquake occurrence and their source characteristics. This alert system has been a useful tool in the warning and information service, both as concerns volcanic and seismic hazards.

Premonitory effects before earthquakes are, however, different at different locations, and for different types of earthquakes. Even if earthquakes occur at approximately the same location, on the same basic fault, crustal conditions may be different, leading to different type of faulting process. This makes it very difficult to detect statistical significance in the precursors if they are only studied as phenomena, like foreshocks or changes in other parameters, without a clear understanding of the physical processes which cause them. In short: It is not enough to observe a certain phenomenon before an earthquake for drawing the conclusion that the same will happen next time. The spatial and temporal crustal conditions will be decisive for which phenomena will be observed before a particular earthquake at a particular site. In order to be able to translate experience from one earthquake to another it is therefore necessary to apply the right parameters to describe the earthquake environment in time and space.

Some significant innovations of the present proposal

Very generally the present proposal aims to enhance earthquake hazard assessment, to provide technology to make it more detailed in space and to enhance the basis for warnings in time.

1) A detailed hazard assessment map

An unexpected observation of the 2000 earthquakes was that seismic activity started almost immediately in a huge area (to distances over 100 km) compared to the size of the earthquake, especially to the west and north of the event. A consequence of this postshock activity was that numerous faults, most likely old earthquake faults were "illuminated" by the activity, making detailed mapping possible. Thus a very detailed mapping of these faults and the slip and slip direction is possible. This is significant for improved hazard assessment, because they are probably future earthquake faults. Modelling this will also throw a new light on the nature of the SW Iceland fault zones and on fault zones in general.

A significant and innovative approach to improve hazard assessment is to base it on the detailed model which will be created about the June 2000 earthquakes.

In general the probabilistic hazard assessment will be improved by multidisciplinary analysis of surface effects, fault mapping, and models constrained by realistic earth parameters, elastic and inelastic, with an innovative methodology.

2) Time dependent hazard assessment

In PREPARED we apply 3 different approaches towards a time dependent assessments of hazard or the state of stress: 1) Long-term build-up of stress due to relatively uniform plate motion, 2) predicted variations in stress loading due to observable strain episodes in adjacent area, and 3) to try with various methods to observe stress or closeness to fracture criticality within the area. In PREPARED all these approaches are applied.

It has been observed through history that large geohazards in Iceland coincide frequently in time. One hypothesis is [30] that there is a common source for this, probably large aseismic events which cause a “strainwave” propagating over a large area. In warning for the second large earthquake in June 2000 a “rule of thumb among the seismologists” was applied, based on experience, that earthquakes in this zone migrate with a velocity of the order of 5 km/day. In this project there is a multidisciplinary approach in trying to define, to test, to explain and then to utilize such apparent connections, based on information carried by microearthquakes, by information from deformation and strain measurements, by radon, and by hydrological observations.

The general innovation here is to develop a method which forecasts how specified observations increase or decrease the probability of a hazard in a given region.

3) Short-term warnings

There are indications of several potential precursors ahead of the June 2000 earthquakes, most prominently by patterns in multiparameter microearthquake information. Such a multiparameter seismic warning algorithm is already applied in the early warning and information system (EWIS) maintained by the coordinator.

In the project intensified work will be carried out to model this and to explain the premonitory activity physically in order to better test the significance of this algorithm and in order to develop new warning algorithms.

Other possible precursory changes involve radon changes, hydrological changes and deformation/strain. The short-term warning potential of these apparently related changes will be studied and compared by developing a source process model that can explain them all.

New multidisciplinary warning algorithms will be based on these studies and models for improving the Icelandic alert/early and warning and information system, based on deeper understanding of the crustal process leading to large earthquakes.

4) New models for strain build-up and strain release in the SISZ

New models will be developed to explain the observed characteristics of individual SISZ earthquakes as well as for the strain build-up and the strain release characteristics in the South Iceland seismic zone and in the Reykjanes peninsula in general. These models will be earth realistic, taking into account inelastic properties below the elastic/brittle crust, intrusions of fluids from depth and poroelastic constitutive relationship, and the enormous amount of new observations available from the June 2000 earthquakes.

This will contribute to improving earthquake hazard assessment, time dependent hazard analysis, as well as to explain causal links among precursory phenomena.

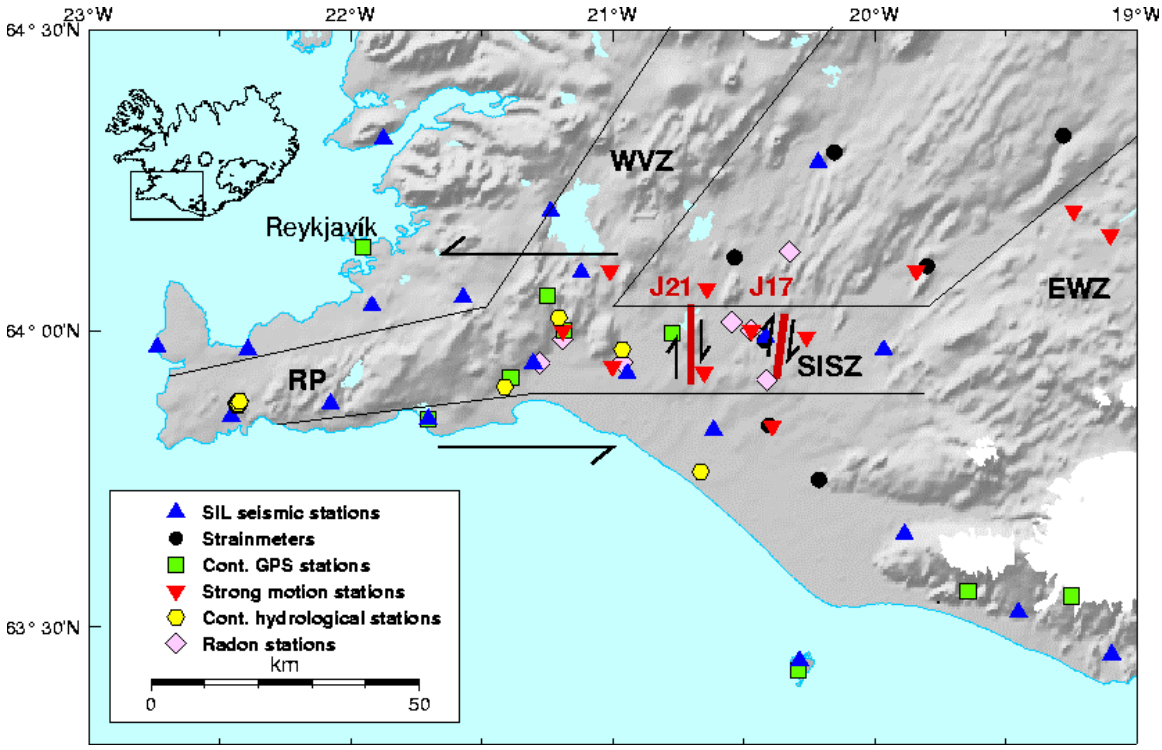


Figure 1. The figure shows the test area for PREPARED, i.e. the South Iceland seismic zone (SISZ) and its prolongation to the west on Reykjanes peninsula (RP). The western volcanic zone (WVZ) and the active eastern volcanic zone (EVZ) are shown. The vertical N-S fault planes of the earthquakes of June 17 and 21 are marked (17, 21). The most significant continuous monitoring stations are indicated.

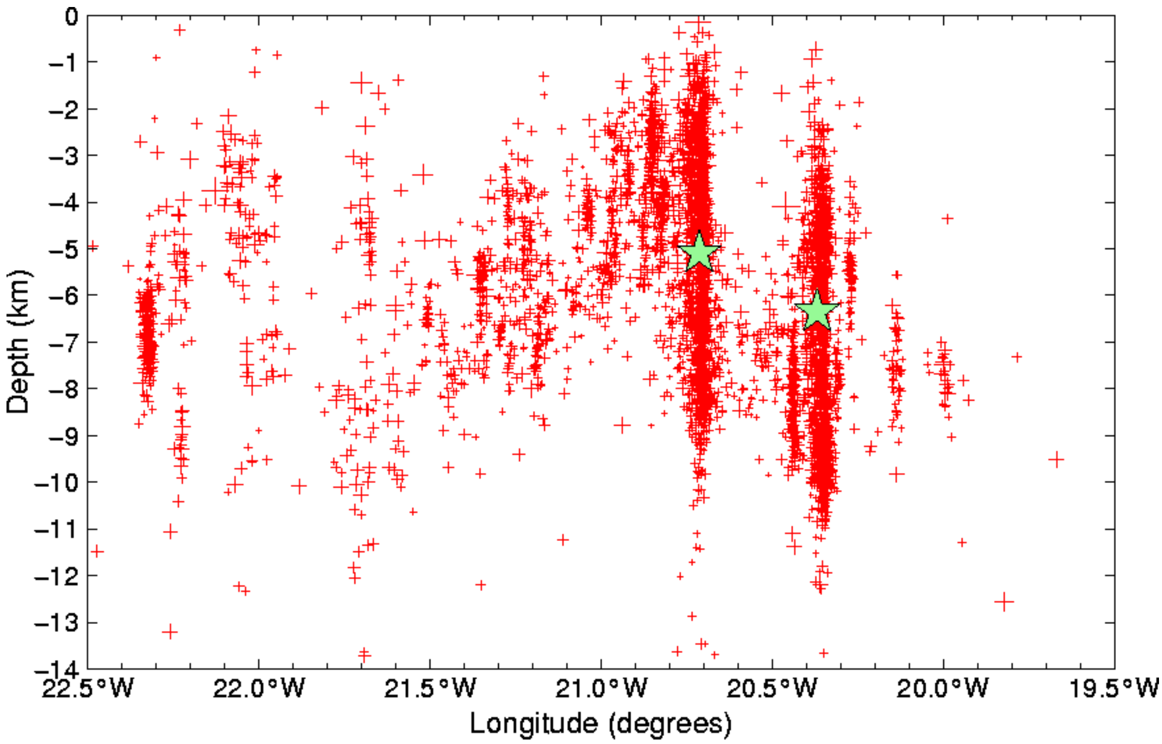


Figure 2. The figure shows a vertical, E-W cross section of the earthquake activity (red crosses) triggered by the large earthquakes (stars) located by conventional methods. The figure demonstrates the enormous potential in the data for detailed mapping of old earthquake faults, by joint interpretation of hypocenter relocation results and fault plane solutions.

B6 Project workplan

The structure of the workplan and the general methodology to achieve the objectives.

The workplan is divided into workclusters or chapters which deal with the various end products of the project, i.e. to approach the different categories of hazard assessments and warnings defined in the objectives. Every workcluster then consists of a few workpackages.

WP 1 Coordination of the project is in the hands of P1. P1 provides a large part of the data used in the project. P1 is also an end user in such a way that he has information and warning duties for the Icelandic state. Parallel with this project P1 runs and operates an early warning and information system in Iceland, which will be a general basis for utilizing observations and understanding of crustal processes for mitigating earthquake and volcanic risk.

WP 2 Analysis of trends in multidisciplinary geophysical data approaching the June 2000 earthquakes. Merging the results of especially WP 2.1-2.5 towards formulating procedures for assessing changes in probability of earthquake hazard based on multiparameter geophysical observations in the earthquake area or based on observed stress loading stemming from changes in adjacent areas.

WP 2.1 and **2.2** will through of different but complementary approaches analyze time and space patterns in seismicity as well as in various information on sources carried by microearthquakes, based on SIL-data since 1991 and to some extent also earlier data.

WP 2.3 Long-term deformation based mainly on GPS, InSAR and volumetric strainmeters during 10-20 years before the earthquakes.

WP 2.4 Stress changes based on microearthquake source information and from geology.

WP 2.5 Applying shear-wave splitting above small earthquakes to monitor stress changes in the SISZ.

WP 3 Short-term changes before the large earthquakes, modelling the changes and testing of short-term warning algorithms. Besides WP 3.1 and 3.2 there are indications of hydrological changes in WP 5.5 and and deformation in WP 2.3 as well as stress induced shear-wave splitting in WP 2.5 which may render information useful for short-term warnings. Short-term warning algorithms will also be based on and tested on basis of detailed monitoring of observed short-term changes before other earthquakes in Iceland.

WP 3.1 Foreshocks. Detailed study of foreshocks before earthquakes for the last 10 years and development of new warning algorithms.

WP 3.2 Radon anomalies. Detailed study of these since 1979, and development of warning algorithm.

WP 4 Detailed model of the two large earthquakes. A group work based on WP 4.1-4.5 lead by the coordinator.

WP 4.1 Focal mechanism, full moment tensor inversion based on teleseismic information. Detailed mapping of fault surfaces and fault motion at depth retrieved from microearthquakes.

WP 4.2 Inversion of near field strong motion data to reveal the slip distribution on the faults.

WP 4.3 Interpretation of surface fractures related to the two large earthquakes.

WP 4.4 Deformation associated with the two large earthquakes, GPS, InSAR, volumetric strain, etc.

WP 5 New methods for improving assessment of probable earthquake effects. A groupwork of participants in WP 5.1-5.5 lead by the coordianator.

WP 5.1 Detailed mapping of distant faults and source processes by microearthquake information in a large area activated by the large earthquakes.

WP 5.2 Detailed mapping of and interpretation of surface ruptures on distant faults and other surface effects caused by the earthquakes in a large area.

WP 5.3 Study of the detailed effects, strong motion records, and intensities, from the large earthquakes.

WP 5.4 Reevaluations of historical earthquakes in light of the new observations.

WP 5.5 Hydrological changes observed in a large area, related to the large earthquakes.

WP 5.6 Analysis of paleo-stress fields and mechanism of faulting for input in hazard assessment.

WP 6 Integration of the modelling work within all the workpackages above with WP 6.1-6.2, for merging a new general model for strain build-up and strain release processes in the SW Iceland seismic zones explaining multidisciplinary parameters.

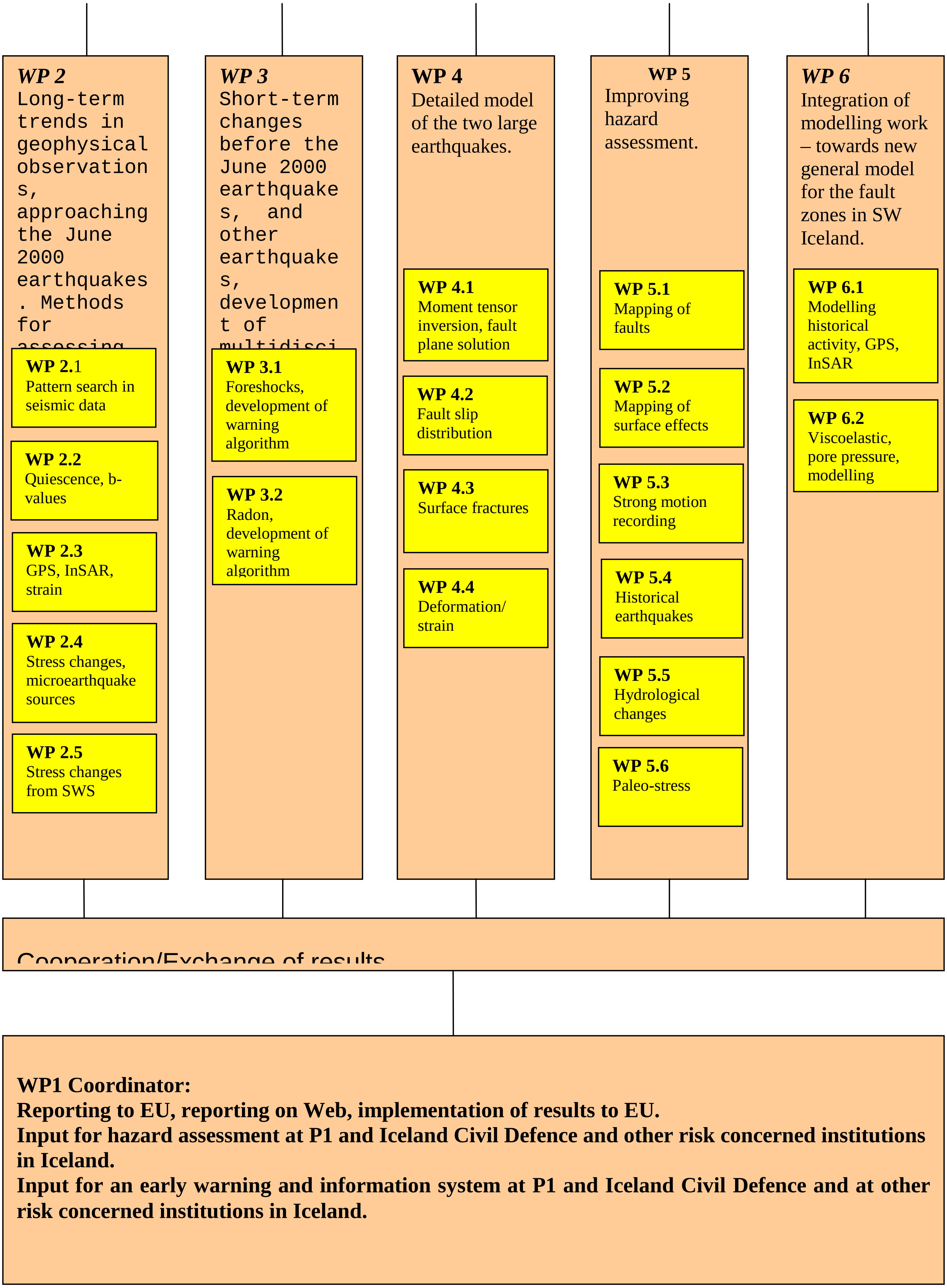
WP 6.1 Model stress changes in Iceland based on historical activity including inelastic properties and Coulomb failure function.

WP 6.2 Model the joint action of stress in the solid matrix and pore pressures in fluids permeating the crust.

Project planning and time table (Gantt Chart)

Workpackage number:	Year 1	Year 2
WP 1 Coordination of the project is in the hands of P1.		
WP 2 Analysis of trends in multidisciplinary geophysical data approaching June 2000.		
WP 2.1 Pattern search in multiparameter seismic data, PCA.		
WP 2.2 Analysis of seismic catalogue, homogeneity, quiescence, b-values.		
WP 2.3 Long-term deformation based mainly on GPS, InSAR and strain.		
WP 2.4 Stress changes based on microearthquake sources and from geology.		
WP 2.5 Shear-wave splitting above small earthquakes to monitor stress changes.		
WP 3 Short-term changes before large earthquakes, short-term warning algorithms.		
WP 3.1 Foreshocks. Detailed study and development of new warning algorithms.		
WP 3.2 Radon anomalies. Detailed study and development of warning algorithms.		
WP 4 Detailed model of the two large earthquakes. A group work.		
WP 4.1 Focal mechanism, based on teleseismic and microearthquake information.		
WP 4.2 Inversion of near field strong motion data. Slip distribution.		
WP 4.3 Interpretation of surface fractures related to the two large earthquakes.		
WP 4.4 Deformation associated with the two large earthquakes, GPS, InSAR, strain.		
WP 5 New methods for improving assessment earthquake effects. A group work.		
WP 5.1 Detailed mapping of distant faults by microearthquakes.		
WP 5.2 Detailed geological mapping of surface effects in a large area.		
WP 5.3 Study of the strong motion records, intensities, from the large earthquakes.		
WP 5.4 Reevaluations of historical earthquakes in light of the new observations.		
WP 5.5 Hydrological changes in a large area related to the earthquakes.		
WP 5.6 Analysis of paleo-stress fields and mechanism.		
WP 6.0 Integration of the modelling work. A new general model.		
WP 6.1 Model stress changes in Iceland based on historical activity.		
WP 6.2 Model stress in the solid matrix and pressures in fluids permeating the crust.		

Graphical presentation of the project´s components



WPL Workpackage list

Workpackage number	Workpackage title	Lead participant	Person-months	Start month	End month	Deliverable No.
WP 1	Overall coordination of the project	P1	15	M0	M24	D1-D6
WP 2	Analysis of multiparameter geophysical data approaching the June 2000 earthquakes, assessing state of stress	P1	8	M0	M24	D7-D12
WP 2.1	Pattern search in multiparameter seismic data	P12	5	M0	M24	D13-D17
WP 2.2	Possible precursory seismic quiescence and b-value changes	P13	8	M0	M24	D18-D19
WP 2.3	Long-term deformation in the South Iceland seismic zone inferred by joint interpretation of GPS, InSAR and borehole strain data	P4	7	M0	M18	D20-D22
WP 2.4	Space and time variations in crustal stress using microearthquake source information from the South Iceland seismic zone (SISZ)	P2	8	M0	M24	D23-D27
WP 2.5	Using shear-wave splitting above small earthquakes to monitor stress in the SISZ	P3	21,5	M0	M24	D28-D35
WP 3	Short-term changes/precursors	P1	4,5	M0	M24	D36-D41
WP 3.1	Foreshocks and development of new warning algorithms	P2	6	M0	M24	D42-D46
WP 3.2	Radon anomalies/Development of warning algorithms	P6	12	M0	M24	D47-D50
WP 4	A model of the release of the two June 2000 earthquakes based on all available observations	P1	5	M0	M24	D51-D55
WP 4.1	Source mechanisms and fault dimensions of the June 17 and June 21 earthquakes determined from inversion of teleseismic body waves and from mapping of aftershocks	P1	17,5	M0	M18	D56-D57
WP 4.2	Analysis, inversion and estimation of strong ground motion data from extended-earthquake fault models of the two June 2000 Iceland events	P11	27	M0	M24	D58-D64
WP 4.3	Surface fractures in the source region of the June 2000 events	P6	12	M0	M20	D65-D70
WP 4.4	Deformation model for the June 2000 earthquakes from joint interpretation of GPS, InSAR and borehole strain data	P4	9	M0	M24	D71-D73
WP 5	New hazard assessment/New methods for improving assessment of probable earthquake effects	P1	4,5	M0	M24	D74-D78
WP 5.1	Mapping subsurface faults in southwestern Iceland with the microearthquakes induced by the June 17 and June 21 earthquakes	P1	15,5	M6	M24	D79-D81
WP 5.2	Mapping and interpretation of earthquake rupture in the Reykjanes peninsula and other surface effects there and in the SISZ	P4	25	M0	M20	D82
WP 5.3	Study of the strong ground motion, acceleration and intensities of the two large earthquakes	P14	17,5	M0	M20	D83-D85
WP 5.4	Reevaluation of the historical earthquakes in light of the new observations	P1	12	M12	M24	D86
WP 5.5	Hydrological changes associated with the June 2000 earthquakes	P5	10	M0	M24	D87-D88
WP 5.6	Paleo-stress fields and mechanics of faulting	P7	11,5	M0	M24	D89-D91
WP 6	Modelling and parameterizing the SW Iceland earthquake release and deformation processes	P1	9,5	M0	M24	D92-D96

WP 6.1	Earthquake probability changes due to stress transfer	P9	34	M0	M24	D97-D98
WP 6.2	Model stress in the solid matrix and pressures in fluids permeating the crust	P8	25	M0	M24	D99-D102

DL Deliverable list

Deliverable Number	Deliverable title	Delivery Date, type, Distribution level
D 1	Start meeting for the project, minutes	M00 Re RE
D 2	Project website, internal, external	M03 Re PU
D 3	Project workshop/meeting, minutes	M10 Re RE
D 4	First annual report	M12 Re PU
D 5	Project workshop/meeting, minutes	M20 Re RE
D 6	Final report	M24 Re PU
D 7	Sessions at regular project meetings or other meetings	M00 Re RE
D 8	Sessions at regular project meetings or other meetings	M12 Re RE
D 9	A special report describing various patterns observed by the different methods	M16 Re PU
D10	Sessions at regular project meetings or other meetings	M18 Re RE
D11	Procedures for describing the state of stress or Coulomb stress conditions in the SISZ	M20 Re PU
D12	A peer-reviewed paper describing the common results	M24 Re PU
D13	Application of PCA to SIL-data, emphasizing computational statistics	M10 Re PU
D14	Application of PCA to SIL-data, emphasizing computational statistics	M12 Re PU
D15	Application of PCA to SIL-data, emphasizing seismology	M22 Re PU
D16	Application of PCA to SIL-data, emphasiszing seismology	M24 Re PU
D17	Release a software package for PCA analysis of seismicity	M24 O PU
D18	Changes of seismicity rate	M12 Re PU
D19	Differences in b-values as a function of space (and possibly time), and the relationship of both of these parameters to the June 2000 main shocks	M24 Re PU
D20	Three-dimensional displacement field in a time-period prior to the June 2000 earthquakes	M12 Re PU
D21	Strain-field in the pre-seismic period	M12 Re PU
D22	Strain-field in the pre-seismic period, evaluation of earthquake precursors	M18 Re PU
D23	Estimates of the stress tensor in the SISZ during 1991 through 2001	M12 Re PU
D24	SAG analysis in the SISZ during 1991 through 2001	M12 Re PU
D25	Estimates of the stress regimes in the SISZ during the last 2-3 million years	M12 Re PU
D26	Results from statistical analysis of source parameters of the earthquakes in the SISZ during 1991 through 2001	M12 Re PU
D27	Stress changes based on microearthquake source information	M24 Re PU
D28	Plots of stress variations before earthquakes and volcanic eruptions	M12/24 Re PU
D29	Stress-forecasts of impending large earthquakes issued to IMOR	Re CO
D30	Report on stress changes estimates by SWS since 1996	M12 Re PU
D31	Reports in collaboration with other partners of imaging stress variations	M12/24 Re PU
D32	Reports on progress of ANN measurements of shear-wave splitting	M12 Re PU
D33	Reports on experience of selecting training sets for ANN	M12 Re PU
D34	Program for measuring SWS with ANN	M24 Re PU
D35	Publication of papers in international research journals	M24 Re PU
D36	Sessions at project meetings and other meetings	M06 Re RE
D37	Sessions at project meetings and other meetings	M12 Re RE
D38	Sessions at project meetings and other meetings	M18 Re RE
D39	A report documenting and comparing multidisciplinary potential precursors of the June 2000 earthquakes	M20 Re PU
D40	Multidisciplinary warning algorithms will be implemented in the Early warning and information system	M22 Re PU
D41	An article in an international scientific journal will be submitted before the end of the project	M24 Re PU
D42	Detailed documentation of the foreshock activity prior to the six largest	M15 Re PU

	earthquakes in Iceland during the last 10 years	
D43	New short-term warning algorithms will be introduced in the Early warning and information system for testing, during the project time	M15 O PU
D44	An article describing the foreshock character, the statistical significance and relation to the various source information	M15 Re PU
D45	A complete automatic earthquake warning algorithm based on the understanding acquired during PREPARED will be presented	M24 O PU
D46	Input of the Early warning and information system for testing at the end of the project to P1	M24 O PU
D47	Time series of radon at all radon stations in South Iceland since 1977	M12 Re PU
D48	Presentation of the radon results at international meetings	M12 Re PU
D49	Paper in a refereed journal on the radon anomalies identified	M20 Re PU
D50	Warning algorithms presented at meeting	M24 Re PU
D51	Sessions at regular project meetings and at other meetings	M06 Re RE
D52	Sessions at regular project meetings and at other meetings	M12 Re RE
D53	Sessions at regular project meetings and at other meetings	M18 Re RE
D54	A report describing the overall model	M20 Re PU
D55	An article describing an overall model	M24 Re PU
D56	A point-source moment tensor solution and source-time function for the earthquakes of June 17 and June 21, 2000	M03 Re PU
D57	Article on the fault dimensions and finer details of possible subfaults, as outlined by the microearthquake distribution. Post-seismic slip-direction as a function of location on the two main faults	M18 Re PU
D58	Preliminary slip model of rupture on the fault of the first earthquake	M08 Re PU
D59	Best slip model of rupture on the fault of the first earthquake	M12 Re PU
D60	Inversion for slip related to the second earthquake	M14 Re PU
D61	Estimated acceleration field in selected localities for first event	M14 Re PU
D62	Preliminary slip model of rupture on the fault of the second event	M18 Re PU
D63	Best slip model of rupture on the fault of the second earthquake	M20 Re PU
D64	Estimated acceleration field in selected localities for a futute event in SISZ and assessment of their damage potential	M24 Re PU
D65	Map of surface fractures in the eastern source area	M06 Re PU
D66	Map of faulting during the June 2000 events	M06 Re PU
D67	Input into the gereral modelling of the June 2000 events	M06 Re PU
D68	Map of fractures in the western source area	M12 Re PU
D69	Presentations of results at international meetings	M12 Re PU
D70	Paper on surface fracturing during the June 2000 events	M20 Re PU
D71	Three-dimensional co-seismic displacement field for June 17 and June 21, 2000 earthquakes	M06 Re PU
D72	Deformation model for the earthquakes	M18 Re PU
D73	Scientific paper with the deformation model results	M24 Re PU
D74	Sessions during project workshop	M01 Re RE
D75	Sessions during project workshop	M10 Re RE
D76	Sessions during project workshop	M20 Re RE
D77	New detailed hazard map of SW Iceland	M22 Re PU
D78	A paper in an international journal	M24 Re PU
D79	Catalog of relocated earthquakes	M18 Re PU
D80	A map of subsurface faults and slip directions on them	M20 Re PU
D81	Article about the mapping and correlations with surface mapping	M24 Re PU
D82	Hazard map of Reykjanes peninsula and accompanying report	M20 Re PU
D83	Attenuation of strong ground motion of the large earthquakes	M12 Re PU
D84	Near source effects, duration of ground shaking and soil amplifications	M18 Re PU
D85	A comprehensive reporting describing the strong motion data, the theoretical modelling, attenuation of strong ground motion and near source effects	M20 Re PU
D86	A revised historical earthquake catalogue for SW Iceland	M24 Re PU
D87	Results from ongoing analytical and numerical modelling	M12 Re PU
D88	Algorithm for detecting possible preseismic signal	M24 Re PU

D89	Report on the stress regimes based on inversion of fault slip data and focal mechanisms of microearthquakes	M22 Da+Re PU
D90	Description and reports on mapped seismic fault segments	M22 Re PU
D91	Description and reports on the numerical modelling experiments applied to the SISZ deformation	M24 Re PU
D92	Session at project meetings, minutes	M01 Re RE
D93	Session at project meetings, minutes on progress	M10 Re RE
D94	Session at project meetings, minutes on progress	M20 Re RE
D95	Report on modelling progress	M22 Re PU
D96	Article on a new model for the SISZ and the RP fault zones	M24 Re PU
D97	Inelastic model for the earthquake series (M>=6) in the SISZ since 1706	M12 Re PU
D98	Article and report: Probability increase of each of these 13 events compared to the model	M24 Re PU
D99	Original mathematical solutions for crack models in trans-tensional environment	M06 Re PU
D100	Crack models in viscoelastic media	M09 Re PU
D101	Crack model in poroelastic (12m) media	M12 Re PU
D102	Article and report on triggered seismicity in terms of dynamic fault interaction	M24 Re PU

WP 1 Overall coordination of the project

Start date or starting event: **M0**
Lead contractor: **P1**
Person-months per participant: **P1 15mo**

1	**Objectives:** Scientific coordination and management of the PREPARED project.
2	**Inputs:** Reports on scientific progress in the various workpackages. Management reports from the contractors. **Methodology / work description:** The coordinator will through organizing workshops/coordinator meetings and special meeting sessions focus this multidisciplinary, multinational project towards results expressed in the objectives. A PREPARED website organized by the coordinator will also be a significant tool for this. The coordinator compiles annual reports based on reports from the contractors. The coordinator, which also provides a significant part of the data will try to ensure the other participants in the consortium with easy access to data and to results. The coordinator which has warning duties in Iceland and which also operates and develops an early warning database will ensure that results of the project will be implemented for risk mitigating purposes in Iceland and be demonstrated for risk mitigating organizations elsewhere.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D1 Start meeting for the project, minutes. M0 Re RE 0,2% D2 Project website, internal, external. M3 Re PU 0,3% D3 Project workshop/meeting, minutes. M10 Re RE 0,4% D4 First annual report. M12 Re PU 1,3% D5 Project workshop/meeting, minutes. M20 Re RE 0,4% D6 Final report. M24 Re PU 2,0%
4	**Milestones:** Delivery of the above items at the date indicated.

WP 2 Analysis of multiparameter geophysical data approaching the June 2000 earthquakes, assessing state of stress

Start date or starting event: **M0**
Lead contractor: **P1**
Person-months per participant: **P1 3mo, P2 1mo, P3 1mo, (P4 1mo), P10 1mo, P12 1mo, P13 1mo**

1	**Objectives:** Analysis and linking together multiparameter geophysical observations expressing stress or strain induced variations with time approaching the June 2000 earthquakes and after these. Explain the possibly common source for these variations. Explain them physically. Formulate procedures to assess increase or decrease in probability of earthquake hazard on basis of observable multiparameter observations.
2	**Input:** Observations and results of evaluations in WP 2.1-2.5. Evolving models and evolving crustal parameters in various other workpackages. **Methodology / work description:** Lead contractors from WP 2.1-2.5 work with the coordinator in a forum for analyzing the multidisciplinary observations. They will also be in close contact with other groups, especially the modellers. In Iceland there are many examples of apparent coupling between hazards at large distances. One attempt to explain this is that strainwaves originating from a large intrusive activity at depth, above the top of the hotspot in the center of Iceland or elsewhere can cause such coincidenses by triggering [30]. Modern geophysical observations have also indicated such links between smaller events. Especially there are several indications of patterns that may be related to the strain build-up before the June 2000 earthquakes. Such patterns in space and time will be searched and analyzed in WP 2.1-2.5 based on observations of microearthquakes, deformation and strain. Combining results of WP 2.1-2.5 and new results of other workpackages, especially the modelling will be applied to formulate procedures to assess the state of stress or increasing probability of earthquakes caused by crustal loading from outside the seismic zones or closeness to fractures criticality within the zone.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D7 Sessions at regular project meetings or other meetings. M0 Re RE 0,4% D8 Sessions at regular project meetings or other meetings. M12 Re RE 0,4% D9 A special report describing various patterns observed by the different methods. M16 Re PU 0,6% D10 Sessions at regular project meetings or other meetings. M18 Re RE 0,4% D11 Procedures for describing the state of stress or Coulomb stress conditions in the SISZ. M20 Re PU 0,5% D12 A peer-reviewed paper describing the common results. M24 Re PU 0,6%
4	**Milestones:** Delivery of the above items at the date indicated.

WP 2.1 Pattern search in multiparameter seismic data	
Start date or starting event: **M0** **Lead contractor :** **P12** **Person-months per participant:** **P12 5mo, (P12 6mo)**	
1	**Objectives:** The occurrence of earthquakes is a complex and highly variable process coupled in space and time. The resulting difficulty to separate superimposed seismicity patterns stemming from different causes impedes the search for anomalies possibly preceding large earthquakes [39]. It has been demonstrated that by a novel approach of Spatio-Temporal Principal Components Analysis (PCA), developed byn the partner, that it is possible to address this problem: in a first application to real data it was possible to unambiguously separate background activity and different individual event sequences for the first time. Furthermore, some constitutents seemingly showed precursory qualities [14]. Within the ideal setting of PREPARED project the objectives are twofold: confirmation and enhancement of the method on the one hand, application to seismicity in the SISZ on the other to detect long- term premonitory changes before the large events in 2000 and to search for precursors of impending events.
2	**Methodology / work description:** The SIL-data since 1991 are of extraordinary quality for this work, with a magnitude completeness seemingly almost down at 0. Within the framework of PREPARED it will be easy to rule out catalogue inconsistencies which might otherwise lead to spurious results. Close collaboration with WP 2.2 will further aid in this and possibly allow utilization of seismicity data from before 1991. After an initial analysis of the complete dataset using existing software, initial results, geological knowledge and data from other workpackages will be incorporated to vary analysis parameters, enhancing the software in the process. Correlation between observed anomalies and the occurrence of large events will finally lead to the establishment of a relation between anomaly characteristics and earthquake parameters. **Work description:** Work in this package will basically comprise familiarization with the existing earthquake catalogue data and subsequent PCA. The first part must also take geological and geophysical constraints such as areas of maximum strain into account, the latter part involves variations in the preparation of the input data as well as enhancement of the existing software. The final step involves the quantification of the PCA results and interpretation of the results with respect to their precursory qualities. PCA of the existing data will commence immediately, if necessary by setting an artificial threshold for the minimum magnitude. With the software existing so far, we will be able to directly analyze epicenter distributions of the SISZ and appropriate subsets thereof, identified by geological knowledge and initial analysis results of the whole area. Depending on results, variations mainly in the preparation of the input data will be carried out: spatial resolution of cells for data gridding, duration of temporal windows for temporal discretization, time shift of windows etc. PCA itself possesses no free parameters which is one of the major advantages of the approach. An extension of the method to include hypocenter depths information will be carried out. The objective delineation and quantification of decomposed constituents (coherent patterns) is a necessary final step which has not been addressed in the qualitative interpretation up to now. The latter step will utilize the functionality of a geographical information system (GIS). We plan the analysis of parameters such as Benioff strain in addition to earthquake rates, also in view of testing the hypotheses of growing correlation length [40] and accelerated seismic moment release [5] which are regarded as promising precursory phenomena.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D13 Application of PCA to SIL-data, emphasizing computational statistics. M10 Re PU 0,5% D14 Application of PCA to SIL-data, emphasizing computational statistics. M12 Re PU 0,5% D15 Application of PCA to SIL-data, emphasizing seismology. M22 Re PU 0,5% D16 Application of PCA to SIL-data, emphasizing seismology. M24 Re PU 0,5% D17 Release a software package for PCA analysis of seismicity. M24 O PU 1,0%
4	**Milestones:** Delivery of the above items at the date indicated.

WP 2.2 Possible precursory seismic quiescence and b-value changes	
Start date or starting event: M0 **Lead contractor: P13** **Person-months per particpant: P13 8mo**	
1	**Objectives:** Determine if the June 2000 earthquakes could have been predicted by precursory seismic quiescence or b-value changes, and what kind of seismicity patterns followed these main shocks.
2	**Methodology/work description**: Map the changes in seismicity rate and in the magnitude frequency distribution as a function of space and time in the South Iceland seismic zone, and evaluate the possible relations of such changes to the M=6.6 main shocks in June 2000. It has been shown that seismicity rates and the b-values of the frequency-magnitude relationship can be changed for years by a major earthquake. Such co-seismic changes are clearly due to a redistribution of stress by the major earthquakes, and can be correlated with the changes in the Coulomb fracture criterion. Precursory changes in seismicity rates also have been documented in many outstandingly strong datasets, but their causal connection to the following main shock is only suggested by the coincidence of the two phenomena in time and space. Precursory decreases in the b-value have been reported by several authors, but truly compelling cases are rare. A co-seismic change was demonstrated with statistical significance in the M=7.2, 1992 Landers earthquake. Close cooperation is planned with WP 2.1, but these two packages complement each other. We plan the following steps of analysis: (**1**) Quantitative analysis of the minimum magnitude of completeness as a function of space and time in the South Iceland seismic zone, together with an analysis of the homogeneity of reporting as a function of time. This type of analysis will take some time and energy, but is necessary to ensure that artificial reporting rate changes do not influence the results. The result of this first step in our analysis is a catalogue that (a) starts at the earliest practical time, (b) extends to the mapped limits of an optimal minimum magnitude of completeness, and (c) is corrected for possible magnitude shifts that may have occurred as a function of time. (**2**) To measure seismicity rate changes as a function of time, earthquake swarms and aftershock sequences must be removed from the catalogue. Usually, we use the parameters in the Reasenberg algorithm [26], which were derived for California. However, it could be that these are not adequate for the seismicity in Iceland, in which case it will cost time and effort to derive the appropriate constants. The product of this second step is a declustered catalogue and a catalogue of clusters. (**3**) In a third step we will map seismicity rate changes as a function of time. (a) We will examine how the June 2000 main shocks have turned off and turned on seismicity in various volumes around them. (b) We will map any possible seismic quiescence that may have preceded these main shocks and we will search all time and space covered by the catalogue for possible other periods of quiescence that might exceed in significance the precursory quiescence. Quiescences near main shocks can only be claimed as possible precursors, if they exceed or at least equal in significance possible periods of quiescence not associated with main shocks. The product of this phase will be case histories of seismicity rate changes related to main shocks in Iceland. (**4**) We will also construct maps of b-value changes with time and of b-value differences as a function of space. Changes with time can seldomly be documented, thus we do not necessarily expect to find them. However, b-value differences in space are ubiquitous and they seem to be related to asperities in fault zones. We propose to test the hypothesis that in Iceland also, volumes that generate major earthquakes are special in that they show low values of the quantity defined as 'local recurrence time' (which is inversely proportional to the annual probability of a main shock of a given magnitude). Up to now, correlation in minima in local recurrence times with main shock locations and asperities identified geodetically exist in central, southern and northern California as well as in Japan and Mexico. The product will be an evaluation of the hypothesis that asperities may be mapped by minima in local recurrence times in Iceland. (**5**) The final step will be modelling of the seismicity rate changes observed. The basis of the models will be changes in the Coulomb fracture criterion. We will seek to correlate such changes due to the main shocks with co- and post main shock rate changes. This work will be done in a different work package.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D18 Changes of seismicity rate. M12 Re PU 1,4% D19 Differences in b-values as a function of space (and possibly time), and the relationship of both of these parameters to the June 2000 main shocks. M24 Re PU 2,4%
4	**Milestones:** Delivery of the above items at the date indicated.

WP 2.3 Long-term deformation in the South Iceland seismic zone inferred by joint interpretation of GPS, InSAR and borehole strain data	
Start date or starting event:	**M0**
Lead contractor:	**P4**
Person-months per participant:	**(P4 6mo), P10 7mo**

1	**Objectives**: 1. To evaluate the long-term three-dimensional deformation field of the Earth in the South Iceland seismic zone prior to 2000 earthquakes, and post-seismic deformation after the earthquakes. 2. To derive a strain rate map for the South Iceland seismic zone prior to the earthquakes. 3. To search for long-term precursor in geodetic signals.
2	**Inputs:** 1. Existing CGPS network. 2. Network GPS measurements. 3. Data from a network of borehole strainmeters. 4. Raw SAR data from ERS, ENVISAT and/or ALOS satellite missions for which we are privileged investigators with access to reduced-price data. 5. Data from electronic distance measurements. 6. Software for analyzing above data. **Methodology / work description:** Geodetic observations perform several roles in the quest for earthquake prediction, including the possibility of recording a precursory signal. Geodetic data is also essential input to models of stress transfer. An extensive geodetic data covering deformation in the SISZ already exists. We will combine all these different data into one unified model for the three-dimensional deformation field in the South Iceland seismic zone prior to the 2000 earthquakes. The data includes 10 continuously recording GPS stations, results from network GPS measurements, a series of InSAR interferograms, going back to 1992, results from a network of borehole strainmeters, and electronic distance measurements. Knowing the displacement field, a strain rate map will be inferred for the seismic zone, that will reveal the spatial distribution of strain in the area. Pre-seismic strain is expected to be highest in the central area of the South Iceland seismic zone, but exact shape of the strain field will be important to understand the earthquakes, and predict where further earthquakes may occur. The data will be explored for potential long-term precursors that might have occurred over years prior to the earthquake sequence, including changes in displacement rates or strain measured by the network of borehole strainmeters.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D20 Three-dimensional displacement field in a time-period prior to the June 2000 earthquakes. M12 Re PU 0,8% D21 Strain-field in the pre-seismic period. M12 Re PU 0,8% D22 Strain-field in the pre-seismic period, evaluation of earthquake precursors. M18 Re PU 1,0%
	Milestones: Delivery of the above items at the date indicated.

WP 2.4 Space and time variations in crustal stress using microearthquake source information from the South Iceland seismic zone

Start date or starting event: **M0**
Lead contractor: **P2**
Person-months per participant: **P2 8mo**

1	**Objectives:** Obtain stress tensor information for the SISZ, prior and after the June 2000 earthquakes, using source information from microearthquakes. Analyze dynamic source parameters in the SISZ during the whole operational period of the SIL-network.
2	**Inputs:** Source and ray path information from more than 100000 microearthquakes in the SISZ from the SIL-database at the Icelandic Meteorological Office (IMOR). Fault slip data collected in the field close to the fault traces of the June 2000 earthquakes and in the whole SISZ. **Methodology / work description:** Two different algorithms [23];[2] will be used to obtain the stress tensor in the SISZ using the available microearthquake focal mechanisms. Spectral Amplitude Grouping (SAG) [24] will be used to analyze the variations in the radiation patterns from the microearthquakes. Relocation of microearthquakes using cross-correlation techniques. Statistical analysis of microearthquke source parameters during the entire period of the operation of the SIL-network. The main focus of this work is to utilize the unique data set provided by the SIL-network prior (10 years), during and after the major earthquakes in June 2000. The uniqueness of the data is due to the low threshold level of the SIL-network (ML=0) and due to the completeness of the routine analysis done in respect to source information of the many small earthquakes. This together with the extensive geological mapping of the surface exposed fractures makes the available data unique for earthquake prediction research. The stress regimes that prevailed in the SISZ area during the last 2-3 millions years will be reconstructed based on systematic inversion of fault slip data, in order to be compared with the present-day stress regimes obtained from focal mechanisms of the earthquakes. The SAG method will be use as a preprocessor on the focal mechanisms data to obtain reliable short-term variations of the stress field. Particular attention will be paid to the short-term variations of the stress state, as related to the propagation of microearthquakes along, and in the vicinity of the main faults. To this end, stress tensors will be computed within narrow 4-D (space-time window). In addition, Coulomb stress models will be established. The June 2000 earthquakes will be the primary target for such analysis. The SAG method will be used to monitor variations in the crustal stress during the period 1991 through 2001. The objective here is to utilize the differential characteristics of the SAG method to monitor changes in the stress field with high resolution, both in time and space. Other methods for the stress tensor estimates will be used and the comparative results will be analyzed and presented. Statistical properties of the source parameter estimates from the SIL-network will be analyzed as well as their relations to the possible physical properties of the deformation processes.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D23 Estimates of the stress tensor in the SISZ during 1991 through 2001. M12 Re PU 0,7% D24 SAG analysis in the SISZ during 1991 through 2001. M12 Re PU 0,7% D25 Estimates of the stress regimes in the SISZ during the last 2-3 million years. M12 Re PU 0,7% D26 Results from statistical analysis of source parameters of the earthquakes in the SISZ during 1991 through 2001. M12 Re PU 0,7% D27 Stress changes based on microearthquake source information. M24 Re PU 1,2%
4	**Milestones:** Delivery of the above items at the date indicated.

WP 2.5 Using shear-wave splitting above small earthquakes to monitor stress in the SISZ	
Start date or starting event: **M0** **Lead contractor:** **P3** **Person-months per participant:** **P3 19mo, P1 2,5mo**	
1	**Objectives:** 1) Continue monitoring shear-wave splitting (SWS) above small earthquakes in SISZ. 2) Evaluation of stress induced SWS changes in SIL-data since 1991, to be correlated with other methods for improved stress-imaging. 3) Identify the build-up of stress (from 1) as a base for stress-forecasts. 4) Develop automatic analysis of shear-wave splitting by artificial neural network (ANN) techniques. 5) Develop training sets for ANN that preserve interpreter's experience for individual seismic stations.
2	**Inputs**: Wave-form data and parameter data from the SIL seismic stations in Iceland. Methodology and experience gained by P3 in stress-forecasting especially in Iceland. **Methodology / work description:** The previous EC Projects PRENLAB-1, PRENLAB-2 and SMSITES monitored shear-wave splitting (SWS) above small earthquakes throughout Iceland and recognized the build-up of stress before earthquakes and volcanic eruptions. This work will be continued. This led to a correct stress forecast of the time and magnitude of an *mb*=5 earthquake in SW Iceland [8]. However, the magnitude *Ms*=6.6 earthquakes in 2000 in the SISZ were not forecast, because of a gap in source seismicity at the near station BJA. Detailed analysis of local stations will test whether forecast could have been made without data from BJA. SWS estimates of stress changes will be correlated with other stress estimates from 1991 before the two *Ms*=6.6 earthquakes and after in order to build up a more complete image of the behaviour of stress in the SISZ and elsewhere. Shear-wave splitting is subject to so many variables that satisfactory automatic measurement of shear-wave on seismograms by analytical techniques is highly unlikely. Artificial neural network (ANN) techniques will be developed to preserve interpreter's experience in SWS. The skill in applying ANN techniques is developed by selection of suitable data-training sets (at each station) so appropriate experience is inserted into ANN. Such ANN training sets will be selected for as many individual SISZ stations as possible. Thus ANN is expected to at least partially automate measuring SWS.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D28 Plots of stress variations before earthquakes and volcanic eruptions M12/24 Re PU 0,7% D29 Stress-forecasts of impending large earthquakes issued to IMOR Re CO 0,6% D30 Report on stress changes estimates by SWS since 1996 M12 Re PU 0,4% D31 Reports in collaboration with other partners of imaging stress variations M12/24 Re PU 0,8% D32 Reports on progress of ANN measurements of shear-wave splitting M12 Re PU 0,4% D33 Reports on experience of selecting training sets for ANN M12 Re PU 0,4% D34 Program for measuring SWS with ANN. M24 Re PU 1,5% D35 Publication of papers in international research journals M24 Re PU 1,0%
4	**Milestones:** Delivery of the above items at the date indicated.

<table>
<tr><td colspan="2">WP 3 Short-term changes/precursors</td></tr>
<tr><td colspan="2">Start date or starting event: M0
Lead contractor: P1
Person-months per participant: P1 3mo, P2 0,5mo, P6 1mo</td></tr>
<tr><td>1</td><td>Objectives:
Analysis of observed short-term changes in various measurements, especially before the large earthquakes. Test and develop multidisciplinary short-term warning algorithms.</td></tr>
<tr><td>2</td><td>Inputs:
Analysis and deliverables of WP 3.1 and WP 3.2. Also related deliverables from several other workpackages of the project which provide results applicable for developing new warning algorithms, such as WP 2.1, 2.2, 2.3, 2.5, 4.1, 5.5 and 6.2.
Methodology / work description:
Automatic warning procedures of different types are already operated by P1. An alert system based mainly on seismicity rate has been operated there for 9 years. New algorithms based on work in the PRENLAB projects have been in operation during the last year. They are based on besides the character of the seismicity also on microearthquake source information and also on wave path information. These warning procedures have shown to be significant, especially for activating and assisting the seismologists in evaluation of signs of possible impending hazards.

WP 3 is a forum for integration of all results of the PREPARED project which can help in developing and testing enhanced short-term warnings. Besides the methods for warnings that will be especially studied in WP 3.1 and WP 3.2, many other workpackages can be expected to rend results which will be significant contribution to this work of deveolping and testing short-term warning methods. To mention examples there were hydrological changes and deformation rate changes before the first earthquake, that possibly may be related to it, which are analyzed in other workpackages.

WP 3 will coordinate these activities in general and work on merging the multidisciplinary methods by analysis and testings into operative warnings algorithms to be implemented into the Icelandic early warning system, and provides information which can help in developing similar warning algorithms into comparable warning systems elsewhere.</td></tr>
<tr><td>3</td><td>Deliverables including cost of deliverable as percentage of total cost of the proposed project:
D36 Sessions at project meetings and other meetiings. M6 Re RE 0,1%
D37 Sessions at project meetings and other meetings. M12 Re RE 0,2%
D38 Sessions at project meetings and other meetings. M18 Re RE 0,1%
D39 A report documenting and comparing multidisciplinary potential precursors of the June 2000 earthquakes. M20 Re PU 0,3%
D40 Multidisciplinary warning algorithms will be implemented in the Early warning and information system. M22 Re PU 0,4%
D41 An article in an international scientific journal will be submitted before the end of the project. M24 Re PU 0,4%</td></tr>
<tr><td>4</td><td>Milestones: Delivery of the above items at the date indicated.</td></tr>
</table>

WP 3.1 Foreshocks and development of new warning algorithms	
Start date or starting event: **M0** **Lead contractor:** **P2** **Person-months per participant: P2 5mo, P1 1mo**	
1	**Objectives:** Detailed study of the foreshock activity and comparing with existing and new models of the earthquake nucleation process leading to the definition of new precursory parameters involving more of the microearthquake source parameters.
2	**Inputs:** The observations are the 6 largest earthquakes within SISZ together with the 175,000 microearthquakes during the period 1990-2001 as recorded by the Icelandic microearthquake network operated by the Icelandic Meteorological Office. All these observations have been inverted for source parameters. **Methodology / work description:** The foreshock activities will be analyzed by use of multievent locations (accurate absolute and relative location in combination with reanalyzed fault plane solutions and dynamic source parameters. Key questions are the role of the foreshocks (concentrating stress or uniforming stress) and their relation to aseismic fault movements (especially accelerating creep). This work will result in detailed physical information about the foreshocks and the crustal processes which will be related to different models of earthquake nucleation. This is expected to lead to new aspects in monitoring the microearthquakes for possible precursory effects. Eventually new earthquake warning parameters will be defined and tested in earthquake warning algorithms.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D42 Detailed documentation of the foreshock activity prior to the six largest earthquakes in Iceland during the last 10 years. M15 Re PU 0,4% D43 New short-term warning algorithms will be introduced in the Early warning and information system for testing, during the project time. M15 O PU 0,6% D44 An article describing the foreshock character, the statistical significance and relation to the various source information. M15 Re PU 0,4% D45 A complete automatic earthquake warning algorithm based on the understanding acquired during PREPARED will be presented. M24 O PU 0,4% D46 Input of the Early warning and information system for testing at the end of the project to P1. M24 O PU 1,2%
4	**Milestones:** Delivery of the above items at the date indicated.

WP 3.2 Radon anomalies / Development of warning algorithms	
Start date or starting event: **M0** **Lead contractor:** **P6** **Person-months per participant:** **P6 12mo**	
1	**Objectives:** To establish the significance of the radon anomalies that occurred prior to the June 2000 earthquakes by comparing them to earlier results of the radon monitoring program in South Iceland and other results world-wide. Characteristics of the anomalies will be determined with the aim of developing a warning algorithm.
2	**Inputs:** 1. Time series of radon at seven sites within the South Iceland seismic zone 1977-1993. 2. Time series of radon at seven sites since 1999. 3. Continuous time series at one site since July 2001 and several sites to be installed in the fall of 2001. **Methodology / work description:** The relationship between radon and earthquakes in this area has been studied since 1977 when Egill Hauksson of the Lamont-Doherty Earth Observatory installed the first equipment for this purpose [17];[18]. The instruments were operated until 1993. A summary of the results until then were given by [20]. A very clear relationship could be established and a number of premonitory radon anomalies were identified. A new instrument was designed and tested for this purpose by [36]. The instrument is based on a novel liquid scintillation technique where counting only Bi-218/Po-218 pulse pairs gives high sensitivity with a simple construction. The system represents a significant progress in the radon measuring technique. A new program of sampling from geothermal wells in the South Iceland seismic zone was initiated in 1999, a year before the destructive earthquakes of June 2000 occurred. The two M=6.5 earthquakes originated in the middle of the sampling network. These events were preceded by clear anomalies at six out of seven stations [37]; see also [21]. This technique is presently being developed further. An automatic system for sampling and analysis has been designed. The first automatic station was installed in July 2001 at the well-head of a drill hole in Selfoss. Other stations will be installed later this year. We plan to hire a research student to study the data from the three data sources listed above, integrate them and do statistical tests. Estimated time is 12 person-months and the work can begin as soon as funds are secured for this project.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D47 Time series of radon at all radon stations in South Iceland since 1977 M12 Re PU 0,8% D48 Presentation of the radon results at international meetings. M12 Re PU 0,5% D49 Paper in a refereed journal on the radon anomalies identified. M20 Re PU 0,4% D50 Warning algorithms presented at meeting. M24 Re PU 1,2%
4	**Milestones:** Delivery of the above items at the date indicated.

WP 4 A model of the release of the two June 2000 earthquakes based on all available observations

Start date or starting event: **M0**
Lead contractor: **P1**
Person-months per participant: **P1 3mo, P2 0,5mo, (P4 0,5mo), P6 0,5mo, P10 1mo, (P11 0,5mo)**

1	**Objectives:** To model the source process in time and space of the two large earthquakes based on multidisciplinary information.
2	**Inputs:** Results and deliverables of WP 4.1, 4.2, 4.3 and 4.4. Results from other WP like the modelling packages 6.1 and 6.2 as well as 5.5. **Methodology / work description:** A significant part of the modelling is a dynamic modelling based on teleseismic data, local seismometer data and acceleration data as described in WP 4.1 and 4.2 which will carry out a full moment tensor inversion assuming point sources and slip distribution on a fault, respectively, i.e. related to the short (several seconds) earthquake process. Observations by microearthquakes and by geological methods will reveal independently the size and the orientation of the fault plane, as well as the detailed postseismic slip and possibly volume changes. Although these observations express process over a longer period of time, they will as well as the various deformation measurements put extra constraints on the short-lived earthquake modelling. Another part of modelling the earthquakes is based on observations of the earthquake process as a process lasting say for weeks, i.e. including besides the short process of release if seismic waves, pre- and postseismic process. This involves the possibility of a significant role of fluids, shallow or from great depth in the earthquake process. Such a modelling is very significant in light of the possibility that such strike-slip earthquakes can be considered a part of a large and longer lasting aseismic process. WP 4 is a forum with representatives from WP 4.1–4.4 as well as from other workpackages in the project, to merge together results and discuss interactively the progress in revealing the overall source process during the project period.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D51 Sessions at regular project meetings and at other meetings. M6 Re RE 0,3% D52 Sessions at regular project meetings and at other meetings. M12 Re RE 0,3% D53 Sessions at regular project meetings and at other meetings. M18 Re RE 0,3% D54 A report describing the overall model. M20 Re PU 0,4% D55 An article describing an overall model. M24 Re PU 0,4%
4	**Milestones:** Delivery of the above items at the date indicated.

WP 4.1 Source mechanisms and fault dimensions of the June 17 and June 21 earthquakes determined from inversion of teleseismic body waves and from mapping of aftershocks	
Start date or starting event: **M0** **Lead contractor:** **P1** **Person-months per participant:** **P1 17mo, P2 0,5mo**	
1	**Objectives:** Determine the source mechanisms and fault dimensions of the two large earthquakes on June 17 (J17) and June 21 (J21), using local and teleseismic body waves. That is: • Obtain a point-source moment tensor solution and source-time function for each of the two large events, as well as search for source directivity in their seismic data. • Define the locations, dimensions and possible sub-fault details in the fault planes of the J17 and J21 earthquakes, by relatively locating the thousands of aftershocks on each of the two faults. • Map the post-seismic slip as a function of location and time on the two large faults in order to understand the evolution of the post-seismic stress.
2	**Inputs**: • Broad-band seismic body waves from J17 and J21, recorded at teleseismic distances on GSN, GEOSCOPE and other available networks. • Around seven thousand microearthquakes on each of the two major faults, recorded by the SIL seismic network in the weeks and months following the two large earthquakes. **Methodology / work description**: • P- and SH-waves from J17 and J21, recorded on broad-band stations at teleseismic (30-90°) distances will be inverted to obtain a moment tensor and source-time function for each earthquake. • Nearly half of the approximately fourteen thousand microearthquakes have yet to be interactively analyzed, to give a good starting location and mechanism for each event. The improved locations will be fed into a multievent relative location algorithm, in order to map the fault dimensions and finer subfault details of J17 and J21. • Combined interpretation of the hypocenter distribution and the possible fault-plane solutions of the individual microearthquakes, in order to study the finer details of post-seismic slip on the two large faults, as a function of time and space.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D56 A point-source moment tensor solution and source-time function for the earthquakes of June 17 and June 21, 2000. M3 Re PU 0,6% D57 Article on the fault dimensions and finer details of possible subfaults, as outlined by the microearthquake distribution. Post-seismic slip-direction as a function of location on the two main faults. M18 Re PU 4,0%
4	**Milestones:** Delivery of the above items at the date indicated.

WP 4.2 Analysis, inversion and estimation of strong ground motion data from extended-earthquake fault models of the two June 2000 Iceland events

Start date or starting event: **M0**
Lead contractor: **P11**
Person-months per participant: P11 24mo, (P11 3mo), P1 1mo, P14 2mo

1

Objectives: 1) Inversion of strong ground motion (accelerograms) data related to the two June 2000 events in Iceland using particular station distributions to retrieve the slip distribution on the fault. 2) Analysis of the reliability of the above inversions using particular station distributions and different physical constraints. 3) Estimation of the strong ground motion due to the June 2000 events in localities with no instrumental recording and assessment of their damage potential, in strong collaboration with Icelandic engineers.

2

Methodology / work description:

1) Methods of inversion of strong ground motion data and analysis of the reliability of the solutions obtained:

During the course of a previous EU funded project (SGME) the method of inversion of seismic data, developed by [9], was further developed and tested. It has been shown that simple least squares solutions are very non-unique and lead to physically unrealistic results, such as adjacent grids on the fault having slip in opposite directions. Constraints, based on the physics of the problem, were introduced in order to reduce the non-uniqueness. The most important constraint was that of non-negativity of the slip rate on the fault. With this, physically reasonable solutions are obtained. Additional constraints such as requiring the scalar seismic moment of the solution to be equal to some prescribed value, say that obtained from the CMT solution or from GPS studies, limiting the maximum fault rupture speed and/or the maximum fault slip speed, etc. were also used. We intend, in the framework of this project, to use and further refine these tested programs (e.g. [3]), in particular to assess the robustness of the inverted solutions and how the robustness depends on the choice of the physical constraints imposed. The programs will be applied to study in detail the energy release on the fault during the two June 2000 earthquakes that occurred in the south of Iceland. We would also like to test and use Empirical Greens Functions (EGF) method to invert the mainshock strong motion data and compare the results with those obtained using theoretical Greens functions in a 1-D anelastic medium.

2) Estimation of strong ground motion for seismic hazard reduction purposes in Iceland:

On the basis of the obtained fault model we plan to estimate the strong ground motion (complete time series records) in localities where the June 2000 events have not been recorded. On the basis of other models of earthquake rupturing that could take place in Iceland in the future – both on the same faults or on adjacent ones (indications to be provided by active tectonic studies in the region) more estimates will be made. This will provide engineers with design time series to be used in the seismic hazard assessment of particular structures and help them in the understanding the observed damage in other localities with no observed ground motion record. In strong connection with the engineering community the damaging potential of such records will be estimated. The relation of damaging potential upon the characteristics of the estimated ground motion and upon the causative scenario event will lead to the worst scenario case. Should the local conditions require it and with certain approximations, we will also estimate the ground motion in 2D anelastic media for some important localities.

3

Deliverables including cost of deliverable as percentage of total cost of the proposed project:

D58	Preliminary slip model of rupture on the fault of the first earthquake.	M8	Re	PU	0,3%
D59	Best slip model of rupture on the fault of the first earthquake.	M12	Re	PU	0,4%
D60	Inversion for slip related to the second earthquake.	M14	Re	PU	0,4%
D61	Estimated acceleration field in selected localities for first event.	M14	Re	PU	0,4%
D62	Preliminary slip model of rupture on the fault of the second event.	M18	Re	PU	0,4%
D63	Best slip model of rupture on the fault of the second earthquake.	M20	Re	PU	0,5%
D64	Estimated acceleration field in selected localities for a future event in SISZ and assessment of their damage potential.	M24	Re	PU	0,9%

4

Milestones: Delivery of the above items at the date indicated.

WP 4.3 Surface fractures in the source region of the June 2000 events	
Start date or starting event: **M0** **Lead contractor:** **P6** **Person-months per participant:** **P6 12mo, (P4 1mo)**	
1	**Objectives:** 1. Cast light on the relationship between surface faulting and faulting at depth during the June 2000 events. 2. Map the surface fractures in the area surrounding the two main faults active in the earthquakes.
2	**Inputs:** 1. Data from previous fracture-mapping projects in the area. 2. Aerial photographs. 3. Historical data. **Methodology / work description:** The epicentral zone of the SISZ shows widespread evidence of recent faulting [13]. Historical documents mention surface faulting during some of the earthquakes, and in the case of the events of 1630, 1784, 1896 and 1912 the fractures have been located and mapped in detail [19]; [12]; [4]. Most of the fractures of 2000 have been mapped as well [6]; [25]. The fractures are grouped into regular arrays, each with N to NE orientation. The arrays are 0.3-3 km long and consist of tension fractures in en echelon arrangement. The tension fractures may be up to a few tens of meters long and have a more easterly orientation than the arrays themselves. Push-up structures are often found between the tips of adjacent fractures. The arrays are lined up in a N-S direction, and are interpreted to reflect underlying right-lateral strike-slip faults. The faults can be traced up to a distance of more than 15 km. Splay faults are sometimes found, branching off from the main faults. Structures resembling those of the 1912, 1896 and 1630 ruptures are found throughout the seismic zone. They can be grouped into systems interpreted to represent faults, more than 25 of which have been identified so far. The faults are transverse to the seismic zone and are arranged side-by-side with spacing of about 1 km between them. We propose to use differential GPS instruments to map in detail the remaining fractures of 2000 as well as all older fractures in the surrounding areas. The maps will be compared with the results of other workpackages, in particular WP, especially 4.1 and 4.4.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D65 Map of surface fractures in the eastern source area. M6 Re PU 0,3% D66 Map of faulting during the June 2000 events. M6 Re PU 0,3% D67 Input into the general modelling of the June 2000 events. M6 Re PU 0,3% D68 Map of fractures in the western source area. M12 Re PU 0,6% D69 Presentations of results at international meetings. M12 Re PU 0,3% D70 Paper on surface fracturing during the June 2000 events. M20 Re PU 1,1%
4	**Milestones:** Delivery of the above items at the date indicated.

WP 4.4 Deformation model for the June 2000 earthquakes from joint interpretation of GPS, INSAR and borehole strain data	
Start date or starting event: **M0** **Lead contractor:** **P4** **Person-months per participant:** **(P4 6mo), P1 1mo, P6 1mo, P10 7mo**	
1	**Objectives:** 1. To evaluate the three-dimensional co-seismic deformation field associated with the June 2000 earthquakes. 2. To derive a deformation model for the earthquakes based on joint interpretation of the all the available geodetic data.
2	**Inputs:** 1. Data from CGPS network. 2. Network GPS measurements. 3. Data from a network of borehole strainmeters. 4. Raw SAR data from ERS. 5. Software for analyzing above data. **Methodology / work description:** Co-seismic deformation field of the June 17 and June 21 earthquakes has been mapped with both network GPS and InSAR. Some observations from continuous GPS and borehole strainmeters do also exist. Initial interpretation of each dataset is already completed with simple dislocation models. Within this workpackage we will develop a unified deformation model based on all the available geodetic data. An elaborate model calling for distributed slip along the fault plane will be determined, using two step inversion. We will first solve for non-linear model parameters (the fault geometry) using simulated annealing and then estimate the fault slip distribution with linear least squares. The distributed slip model based on geodetic measurements will be an important element into a unified model for the earthquakes.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D71 Three-dimensional co-seismic displacement field for June 17 and June 21, 2000 earthquakes. M6 Re PU 0,5% D72 Deformation model for the earthquakes. M18 Re PU 1,5% D73 Scientific paper with the deformation model results. M24 Re PU 1,4%
4	**Milestones:** Delivery of the above items at the date indicated.

WP 5 New hazard assessment/New methods for improving assessment of probable earthquake effects

Start date or starting event: **M0**
Lead contractor: **P1**
Person-months per participant: **P1 3mo, (P4 0,5mo), P5 0,5mo, P7 0,5mo, (P11 0,5mo), P14 0,5mo**

1	**Objectives:** On basis of the unique observations made in relation to the June 2000 earthquakes in the SISZ as well as on basis of results of modelling the earthquake sources in time and space we aim towards a more detailed hazard assessment both as concerns the the location and severity of probable earthquake hazard. This improvement is very significant basis for general risk assessment.
2	**Methodology / work description:** Probable faults of future large earthquakes will be mapped in detail. Following the June 2000 earthquakes an area of 100 km length along the South Iceland seismic zone and the Reykjanes peninsula, and to some extent towards north, was activated by triggered activity of small earthquakes, reflecting fault movements on numerous faults, which either were not known before or not accurately known. Data and methodology is now available for accurate mapping of these fault at depth by microearthquakes information, to be compared with geological mapping of faults on the surface. Digital strong motion records near the origin complemented with information on surface effects mapped by geologists and intensities on basis of questionnaires will improve the basis for detailed expected hazard mapping. Drastic changes in ground water and geothermal water systems in the area were observed, especially following the June 2000 earthquakes. These will be analyzed and compared to the detailed models of the earthquakes to understand better the relation between such earthquakes and hydrological changes. New intepretation of historical information: A significant part of the workpackage is to compare the detailed information which we have about the June 2000 earthquakes with historical informaton and thus to try to confirm or modify earlier intepretations of the historical activity. WP 5 will operate like a forum consisting of representants from WP 5.1-5.6 and WP 4.2 for integrating the results from the multidisciplinary work. Most of the workpackages of the project will produce results which can be applied here, not least the modelling packages WP 6.1 and WP 6.2.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D74 Sessions during project workshop. M1 Re RE 0,2% D75 Sessions during project workshop. M10 Re RE 0,2% D76 Sessions during project workshop. M20 Re RE 0,2% D77 New detailed hazard map of SW Iceland. M22 Re PU 0,5% D78 A paper in international journal. M24 Re PU 0,4%
4	**Milestones:** Delivery of the above items at the date indicated.

<table>
<tr><td colspan="2">WP 5.1 Mapping subsurface faults in southwestern Iceland with the microearthquakes induced by the June 17 and June 21 earthquakes</td></tr>
<tr><td colspan="2">Start date or starting event: M6
Lead contractor: P1
Person-months per participant: P1 15mo, P2 0,5mo</td></tr>
<tr><td>1</td><td>Objectives:
To map the subsurface fault planes and slip directions on those faults in southwestern Iceland that were illuminated by the microseismicity induced by the June 17 (J17) and June 21 (J21) earthquakes. This includes faults within and around the South Iceland seismic zone, as well as within the rift zone on Reykjanes peninsula. Thousands of smaller earthquakes followed J17 and J21, induced either by the seismic waves propagating from the two, or by the slower propagating change in stress field, resulting from the large (roughly 1 m) slips on their several kilometer long faults. The map is a significant input to the detailed hazard map, which will be prepared in the project, as closeness to active faults is critical for the ground motion of the shallow earthquakes in South Iceland. The map is also a necessary input for modelling the stress field changes in time and space.</td></tr>
<tr><td>2</td><td>Inputs:
• Around eight thousand microearthquakes recorded by the SIL seismic network in the weeks and months following J17 and J21.
• Algorithms
a) for simultaneously determining accurate multi-event relative locations, as well as improved absolute locations. Greatest accuracy is achieved by cross correlating similar waveforms at each station and inverting the matrix of differences in arrival-time-residuals between earthquakes.
b) for simultaneously interpreting event distributions and fault-plane solutions of the individual events, in order to determine which events from a cluster can define a common fault.
Methodology / work description:
Approximately half of the eight thousand events have yet to be interactively analyzed, to give a good starting location and mechanism for each event. When this has been accomplished, the multi-event relative relocation method will be applied to the dataset in order to increase the location accuracy to such a degree that individual fault patterns become resolvable. The new event distribution therefore, has the ability to define common fault planes. When interpreted together with the possible focal mechanisms for each event, it becomes possible to distinguish between physically possible faults and impossible clusters. The methods used to achieve this will consist of statistical and fuzzy logic methods. Finally the faults and slip directions on them will be compiled into a tectonic map for the area.</td></tr>
<tr><td>3</td><td>Deliverables including cost of deliverable as percentage of total cost of the proposed project:
D79 Catalog of relocated earthquakes. M18 Re PU 2,6%
D80 A map of subsurface faults and slip directions on them. M20 Re PU 1,0%
D81 Article about the mapping and correlations with surface mapping M24 Re PU 0,5%</td></tr>
<tr><td>4</td><td>Milestones: Delivery of the above items at the date indicated.</td></tr>
</table>

WP 5.2 Mapping and interpretation of earthquake rupture in the Reykjanes peninsula and other surface effects there and in the SISZ	
Start date or starting event:	**M0**
Lead contractor :	**P4**
Person-months per participant:	**P4 24mo, P1 1mo**

1	**Objectives:** To identify distant faults (on the Reykjanes peninsula) whose movement was triggered by the 17 June, 2000 earthquake in the South Iceland lowland. To map the extent of surface rupture along these distant faults and other surface effects (rock fall and slope failure) in the entire area of SISZ and the Reykjanes peninsula. To characterize the faults along which motion was triggered in order to determine future predictability of minor fault movements.
2	**Inputs:** Existing and evolving seismic data (from the SIL-network) and existing GPS data Existing knowledge about faults in the area Georeferenced aerial photographs and geological maps Fieldwork, to include mapping with Differential GPS unit Geographic Information Systems software (Arc/Info, Trimble Pathfinder, Erdas Imagine). **Methodology / work description:** Within minutes of the M=6.6 earthquake in South Iceland on June 17, 2000, smaller earthquakes occurred along a 100 km length of the plate boundary to the west of the main shock. The entire length of the Reykjanes peninsula was affected. The largest was a 4.8 Mw shock 85 km west of the mainshock. Rock fall was observed and reported over a wide area in the central part of Reykjanes peninsula, and surface rupture has been observed in several places. Most of the small earthquakes occurred at shallow depths (< 5 km) along pre-existing faults. At least two faults in the Krýsuvík area experienced significant movement, while many others show evidence of minor movement or shaking. Interferometry has shown that a fault centered under Lake Kleifarvatn has experienced as much as 1 m of aseismic slip and is the probably cause of water draining out of the lake at the rate of 9 mm per day. Slope failure and large rock fall has occurred along many steep scarps in the vicinity of Lake Kleifarvatn. GIS has been used to identify areas where clusters of small earthquakes (M < 2) or single events (M=2) have occurred along the strike of pre-existing faults. Some fieldwork has been conducted in those areas to determine the surface manifestations of the seismicity. This part of Reykjanes peninsula is in close proximity to the greater Reykjavík area, including Hafnarfjördur and the nearby Straumsvík aluminum smelting facility. The area of highest seismicity is being newly exploited for geothermal energy and increasing numbers of summer homes are being built there. Criteria will be developed to evaluate the degree of potential hazard to the various users of the area. Additional fieldwork is required to cover the areas affected by small, shallow earthquakes and to map in detail areas of ground rupture, rock fall and slope failure. Results from detailed field mapping will be integrated with geophysical data using GIS software to develop a hazard map for Reykjanes peninsula. These data will also provide a test for dynamic models of Coulomb stress change resulting from earthquakes in the South Iceland lowland.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D82 Hazard map of Reykjanes peninsula and accompanying report. M20 Re PU 6,0%
4	**Milestones:** Delivery of the above items at the milestone date indicated.

WP 5.3 Study of the strong ground motion, acceleration and intensities of the two large earthquakes	
Start date or starting event: **M0** **Lead contractor:** **P14** **Person-months per participant:** **P14 16,5mo, P1 1mo**	
1	**Objectives:** To study strong ground motion by applying recordings of the 2000 earthquakes, emphasizing attenuation and duration. Special attention will be given to the strong ground motion in the near source area.
2	**Inputs:** Main source of data: Strong ground motion recordings from 32 ground response stations, thereof 17 in and near the SISZ of earthquakes in the area. Additional data considered: Seismometer data from more than 30 stations in all of Iceland. Replies to questionnaires about felt intensities in the 2000 earthquakes. Information on seismic and geological structure. **Methodology / work description:** Based on digital recordings from tri-axial accelerometers in earthquakes in South Iceland mathematical models are derived which describe the strong ground motion. These models are necessary for microzonation and for simulating realistic input records to computational structural models. The models account for the variability in the ground motion with respect to factors such as direction to fault, directivity and soil amplification. The mathematical models are based on an analytical approach in contrast to the empirical approach commonly applied.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D83 Attenuation of strong ground motion of the large earthquakes. M12 Re PU 1,2% D84 Near source effects, duration of ground shaking and soil amplifications. M18 Re PU 2,0% D85 A comprehensive reporting describing the strong motion data, the theoretical modelling, attenuation of strong ground motion and near source effects. M20 Re PU 2,8%
4	**Milestones:** Delivery of the above items at the date indicated.

WP 5.4 Reevaluation of the historical earthquakes in light of the new observations	
Start date or starting event:	M12
Lead contractor:	**P1**
Person-months per participant:	**P1 11mo, (P11 1mo), P14 1mo**

1	**Objectives:** The aim of the project is to reevaluate magnitudes, locations and possible fault size for historical events in the South Iceland seismic zone back to 1700.
2	**Inputs:** Estimation of damages caused by historical earthquakes and original documents. Available information about faults related to known historical earthquakes. Surface ruptures and other surface effects caused by the 2000 earthquakes. Questionnaires distributed after the earthquakes on June 17 and 21, 2000. Acceleration (WP 5.3). Detailed dynamic modelling of the year 2000 earthquakes emerging from other workpackages. Earlier evaluations of the intensities/magnitudes and a database of the historical earthquakes. **Methodology / work description:** Previous estimates of magnitudes and locations of historical events are based on the area of damage zone (defined where at least half of all houses collapsed), the Icelandic formula for attenuation of intensities and the instrumentally observed magnitude (Ms=7.0) of an earthquake in the SISZ 1912. For the recent events we have detailed information about the earthquakes, exact locations, fault geometry and slip. The effects of the earthquakes (surface faulting and intensities) are also far better known than for the historical events and now we have in addition acceleration records. Some historical documents will be reanalyzed for estimating intensities. A comparison of detailed information from the 2000 earthquakes with incomplete data from the historical events gives the possibility to revaluate magnitudes, location and fault size of the historical events and thus make improved hazard assessment possible.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D86 A revised historical earthquake catalogue for SW Iceland. M24 Re PU 3,4%
4	**Milestones:** Delivery of the above items at the date indicated.

WP 5.5 Hydrological changes associated with the June 2000 earthquakes	
Start date or starting event: M0 **Lead contractor: P5** **Person-months per participant: P5 8,5mo, (P5 21mo), P1 0,5mo, P7 1mo**	
1	**Objectives:** 1) To explain the observed drastic changes in the ground water and geothermal water systems and correlate these changes with the June 2000 earthquakes. 2) To contribute to forecasting future large earthquakes in the SISZ through modelling and 3) predicting preseismic hydraulic changes in the upstream and downstream parts of an eventual fault plane.
2	**Inputs:** 1) Data on changes in geothermal and groundwater systems in South Iceland in relation to the June 2000 earthquakes from subcontractor in Iceland. 2) From the same subcontractor televiewer measurements and analysis of the boreholes which now are used for the continuous monitoring of hydrological changes in the SISZ. 3) Earthquake distribution just prior to and following the June 2000 earthquakes, from P1 to understand the coupling between fluid flow and seismicity, particularly the aftershock distribution. 4) Field observations (from various places) and numerical models of propagation and arrest of hydrofractures in layered, jointed and faulted rock masses with various mechanical properties. **Methodology / work description:** 1) Boundary element, finite element and finite difference programs will be used to model the flow of overpressured fluids through the layered, jointed and faulted crust of the SISZ and permeability changes prior to and following the June earthquakes. A preliminary study for a homogeneous and isotropic crust indicates that the drastic water-level changes in geothermal drillholes can be broadly related to permeability changes in the upstream and downstream regions of the earthquake ruptures. 2) Preseismic flow of fluids to, and accumulation on, the eventual rupture zones will be modelled using standard hydrogeological programs and the numerical programs for modelling fluid flow in fractures. 3) The same programs will be applied to model the postseismic flow of fluids to the tipline of the mainshock fault planes. 4) Preliminary models [15] indicate that when the trend of an active fault coincides with that of the local hydraulic gradient, the yield of springs and wells in the upstream part decreases but increases in the downstream part. This model will be developed so as to help forecast future large earthquakes in the SISZ, i.e. to try to detect possible preseismic changes by observing hydrological changes. 5) The results of the models and measurements will be used to explain the hydrological changes associated with the June 2000 earthquakes.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D87 Results from ongoing analytical and numerical modelling. M12 Re PU 3,0% D88 Algorithm for detecting possible preseismic signal. M24 Re PU 5,0%
4	**Milestones:** Delivery of the above items at the date indicated.

WP 5.6 Paleo-stress fields and mechanics of faulting

Start date or starting event: **M0**
Lead contractor: **P7**
Person-months per participant: **P7 11,5mo**

1	**Objectives:** Description of stress fields and understanding of the mechanical behaviour of an active seismogenic zone, the South Iceland seismic zone (SISZ), based on: (a) systematic inversion of fault slip data and focal mechanisms of earthquakes. (b) structural study of faulting. (c) numerical modelling of deformation and stress-strain relationships.
2	**Inputs:** • Existing fault slip data in the South Iceland seimic zone, to be compiled with additional detailed collection in the field close to the fault traces of the 2000 earthquakes. • Analysis of already acquired GPS mapping of typical earthquake faults and fissures, for recent earthquakes and historical-prehistorical ones. • Existing aerial photographs in the South Iceland seimic zone. **Methodology / work description:** • Inversion of fault slip data to obtain the stress tensor [1] and of double-couple earthquake focal mechanisms (from the SIL-network) to obtain the stress tensor without choice among nodal planes [2]. • Analysis of surface features of faults (mapping and geometrical analysis). • Numerical modelling softwares (distinct-element, finite-element). **Description of the work:** A large number of data, geological and seismological has been acquired in the SISZ; that deserve detailed analysis, which has not been fully done yet, and provide a firm basis for a deeper understanding of the active, co-seismic deformation and hence for a better appraisal of the earthquake nucleation processes. The stress regimes that prevailed in the SISZ area during the last 2-3 millions years will be reconstructed based on systematic inversion of fault slip data, in order to be compared with the present-day stress regimes obtained from focal mechanisms of earthquakes. It is thus possible to determine how did the crustal stress change in space and time near a fault that was later activated during a major earthquake (e.g. the Árnes and Hestfjall faults of the major June 17 and 21 earthquakes, 2000) To this respect, a contribution to the mapping of the faults of the SISZ will be brought, as an attempt at combining mechanisms and structural pattern rather than a mere description of the fault traces. For this reason, our study of fault traces is focussed on selected areas where the brittle mechanisms can be reconstructed from both the geological and seismological observations. Numerical modelling will be carried out in a systematic way, in order to reproduce the actual deformation of the SISZ with simple boundary conditions and realistic thermal patterns. This modelling work will take advantage of both the large mass of data that already exists.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D89 Report on the stress regimes based on inversion of fault slip data and focal mechanisms of microearthquakes. M22 Da+Re PU 3,8% D90 Description and reports on mapped seismic fault segments. M22 Re PU 2,0% D91 Description and reports on the numerical modelling experiments applied to the SISZ deformation. M24 Re PU 2,0%
4	**Milestones:** Delivery of the above items at the date indicated.

WP 6 Modelling and parameterizing the SW Iceland earthquake release and deformation processes

Start date or starting event: **M0**
Lead contractor: **P1 in close cooperation with P6**
Person-months per participant: **P1 3mo, P6 1,5mo, P8 1mo, P9 1mo, P10 3mo**

1	**Objectives:** Modelling and parameterizing the strain build-up and strain release in the SW Iceland earthquake zones on basis of all available relevant multidisciplinary data.
2	**Inputs**: Progress and results of WP 6.1 and 6.2. Progress and results of other workpackages parameterizing or modelling on basis of various observations. **Methodology / work description:** Several models have been created to describe faulting in the South Iceland seismic zone, models which explain significant observations of geophysics and geology. The June 2000 earthquakes yield new information which constrain such a model. WP 6.1 and 6.2 will continue modelling work carried out within the PRENLAB projects, fulfilling more multidisciplinary information, and especially observations of the June 2000 earthquakes. The workpackage leaders together with representatives of WP 6.1 and WP 6.2 will create a forum with other partners of the consortium to discuss and to merge a general model of the area. It will inform the participants about emerging results regarding the general characteristics of the SISZ and the linked Reykjanes peninsula, so they can be applied directly in the various workpackages.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D92 Session at project meetings, minutes. M1 Re RE 0,4% D93 Session at project meetings, minutes on progress. M10 Re RE 0,4% D94 Session at project meetings, minutes on progress. M20 Re RE 0,4% D95 Report on modelling progress. M22 Re PU 0,8% D96 Article on a new model for the SISZ and the RP fault zones. M24 Re PU 1,2%
4	**Milestones:** Delivery of the above items at the date indicated.

WP 6.1 Earthquake probability changes due to stress transfer

Start date or starting event: **M0**
Lead contractor: **P9**
Person-months per participant: **P9 30mo, P10 4mo**

1	**Objectives:** Improving probabilistic earthquake hazard assessment through stress field models for media with both elastic and inelastic layers. Achieving a time-dependent hazard analysis by deducing changes in the probability of future earthquakes due to stress transfer.
2	**Inputs:** • The historical seismicity in the region are needed and exist, • Data on the aftershock activity of recent strong events are needed and available too, the same is true for the deformation fields obtained from Continuous GPS and INSAR. **Methodology / work description:** The models of stress changes due to strong earthquakes in the South Iceland seismic zone (SISZ) produced in the framework of the EU-funded projects PRENLAB-1 and PRENLAB-2 will be extended to include inelastic behaviour. The stresses will be calculated with the elasticity theory of dislocations for a layered elastic/inelastic medium using existing programs of [27]). The algorithms were fully redesigned by [38] and then extended to inelastic medium properties for layers below the seismogenic layer. By this, now changes in the stress field due to plate motion, from seismic events, from stress relaxation and aseismic slip/creep can be taken into account. Moreover, we will now consider - besides the variations in the shear stress distribution - also the changes in the Coulomb failure stress (CFS), as these have shown to correlate well with aftershock distributions and - in some cases - with stress transfer in series of strong events. Coulomb stresses will be determined expanding a fully elastic approach of [22] to inelastic constitutive laws using own software. Both, the shear stress and the Coulomb stress variations, will be converted into an increase/decrease of changes in the occurrence probability of future earthquakes (a permanent offset plus a temporal increase for the aftershock period). Time-dependent earthquake probabilities on fault segments near those that ruptured recently (e.g. in June 2000) will be calculated by two methods: (i) the stationary Poisson model and (ii) the conditional probability model [16]; [7]. Following the approach of [35], permanent and transient effects - determined via the rate and state dependent fault property model of [10] and [11] - of stress changes are taken into consideration. The recurrence rate of earthquakes in the SISZ determined via the long-term moment release will be used to check whether the historical events show stress triggering. For the present situation (time period of the project), the probability of a strong event in parts of the SISZ that did not rupture for a long time is recalculated using the stress transfer method. Results of the research activities in PRENLAB and PRENLAB-2 are now extended and used to provide an important contribution to an early warning and information system. Close cooperation will be with WP 6.2 and with WP 2.3, 2.4, 2.5, 4.4 and 4.5.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D97 Inelastic model for the earthquake series (M>=6) in the SISZ since 1706. M12 Re PU 2,5% D98 Article and report: Probability increase of each of these 13 events compared to the model. M24 Re PU 2,5%
4	**Milestones:** Delivery of the above items at the date indicated.

WP 6.2 Model stress in the solid matrix and pressures in fluids permeating the crust	
Start date or starting event: **M0** **Lead contractor:** **P8** **Person-months per participant:** **P8 21mo, P10 4mo**	
1	**Objectives:** 1) To model the lithosphere-asthenosphere interaction under the SISZ, taking into account viscoelastic constitutive relationships and intrusion events across rheological discontinuities. 2) To model crust instability in the SISZ taking into account poro-elastic constitutive relationships. 3) To model triggered seismicity and the interaction between the two large earthquakes of year 2000.
2	**Methodology / work description:** In the framework of previous research within the Environment Program of the EU, rigorous mathematical solutions of dislocation problems in elastic layered media have been obtained which have shown that rigidity contrasts can be responsible for significant stress build-up localized along the interface between different media. Due to the different geometrical configurations, strike-slip, dip-slip and pull-apart motions across heterogeneous media have very different effects on the stress field and on failure conditions. Further studies of such effects have shown that fault complexities must inevitably be generated in nascent transform zones, since it is not generally possible to prescribe the stress drop on one planar fault without violating the welded B.C. Models produced up to now were restricted to elastic heterogeneous media, so that applications were mainly oriented to describe co-seismic and early post-seismic effects of faulting. In the preparatory stage of an earthquake, different constitutive relationships should be considered. First, viscoelastic constitutive relationships should be employed to model a subcrustal asthenosphere under the SISZ. If the asthenosphere is modelled in terms of the SLS rheology (Standard Linear Solid), its long-term rigidity is much less than the instantaneous rigidity inferred from seismic waves: accordingly we expect that very high stress concentration may arise along the brittle side of the interface following spreading motions in the asthenosphere. Second, poroelastic constitutive relationships should be employed to model the joint action of stress in the solid matrix and pore-pressure in the fluids permeating the crust. According to the modified Coulomb-Navier criterion, failure conditions are sensitive to both, stress and pore-pressure, but most studies up to now have not considered the possibility that sources of pore pressure may be present in the crust, related to exsolution of volatiles from ascending magma in the asthenosphere. Third, fault interactions studies provide a contribution to the understanding of the physical processes at the base of earthquakes sequences. In particular the explanation of short-term and long-range interactions can rely upon the study of the dynamic stress redistribution during the sequence studied. After the first magnitude 6.6 earthquake of 2000, a series of earthquakes followed immediately to a distance of 100 km along the SISZ and it prolongation along the Reykjanes peninsula (RP). The local seismic data and aftershock data collected in the SISZ can be used as a basis for dynamic detailed modelling of fault interactions. The results of such modelling and the use of fault constitutive properties, such as the rate- and state-dependent friction laws, can enable us to understand the triggered seismicity. The seismic events which took place in year 2000 within the SISZ offer a unique opportunity to test these models, increase our understanding of preparatory phases of earthquakes and of triggered seismicity. This will in turn provide a quantitative conceptual scheme in the framework of fault mechanics, capable of explaining causal links among precursory phenomena.
3	**Deliverables including cost of deliverable as percentage of total cost of the proposed project:** D99 Original mathematical solutions for crack models in trans-tensional environment — M6 Re PU 1,0% D100 Crack models in viscoelastic media. — M9 Re PU 1,0% D101 Crack model in poroelastic (12 m) media. — M12 Re PU 1,0% D102 Article and report on triggered seismicity in terms of dynamic fault interaction. — M24 Re PU 2,0%
4	**Milestones:** Delivery of the above items at the date indicated.

C1 Title page

Application of practical experience gained from two recent large earthquakes in the South Iceland seismic zone in the context of earthquake prediction research to develop technology for improving preparedness and mitigating risk

PREPARED

Energy, Environment and Sustainable Development

Part A: Environment and Sustainable Development

October 12, 2001

C2 Contents

C3 Community added value and contribution to EU policies

Long-term European cooperation in advancing methods for mitigating risks in the "Iceland Natural Laboratory"

The project aims at preparedness towards earthquake hazards, towards mitigating seismic risk.

It addresses the questions of assessing what earthquake effects may occur at any place. It prepares for various types of warnings to be issued ahead of an earthquake. It prepares for various types of rescue actions after the earthquake has occurred. It develops close relationship with the an early warning and information system in Iceland and with the National Civil Defence of Iceland.

The PREPARED project is a continuation of European activities for mitigating seismic risk. In the early eighties an AD HOC committee, operating on behalf of the Council of Europe, pointed the South Iceland lowland area as a test area for multinational approach to earthquake prediction research.

This was the initiation of the SIL-project which was a cooperative research project of the Nordic Countries in this field in 1988-1995. The main achievement of the SIL-project was the high-level seismic automatic acquisition and evaluation system operating in whole Iceland now, i.e. the SIL-system.

The SIL-system was in many ways the basis for the PRENLAB projects of the European Union, PRENLAB in 1996-1998 and PRENLAB–2 in 1998-2000. PRENLAB was an acronym for "Earthquake-Prediction Research in a Natural Laboratory", i.e. Iceland.

In the SIL-project as well as in the PRENLAB projects the basic ideas were to make a progress towards better warnings about large and dangerous earthquakes; concerning time, place and severity, a physical approach was necessary. It was necessary to understand better the processes leading to and involved in large earthquakes. For this a multidisciplinary approach was necessary.

"The Iceland Natural Laboratory for Earthquake Prediction Research" is significant for PREPARED. The natural conditions in Iceland for studying deformations and fault movements in real-time are now complemented with extremely high-level technology to do this, technology which is in the forefront in the world. The SIL microearthquake system, as well as progress in applying space technology for deformation monitoring, like GPS and InSAR are well known in the international scientific world.

The earthquakes in the South Iceland seismic zone known from history to be catastrophal were the basis for the Icelandic and European efforts towards earthquake prediction research for mitigating risk. The European efforts in this area are a basis for the PREPARED project, which is applying the earlier research results for direct procedures for risk mitigation, from short-term warnings to hazard assessments.

Successes in hazard assessments and short-term warnings about impending earthquakes testified the significance of the results of the research and technological development

The magnitude 6.6 earthquakes in the South Iceland seismic zone in June 2000 came at the end of the PRENLAB–2 project and were on one hand a test for the understanding accumulated in these research projects and on the other hand they provided a unique dataset for bringing the results of the earlier research further, towards practical applications for mitigating risk.

Limited destruction caused by these earthquakes, and no serious casualties of people testified the significance of earth sciences and earthquake engineering in providing risk mitigating information.

A warning, correct on size and location of the most hazardous area, which was issued by the seismologists at the Icelandic Meteorological Office, 25 hours before the second earthquake, helped to encourage scientists as well as the public and government that useful earthquake warnings are possible. A successful and very useful warning issued in cooperation of the seismologists at the Icelandic Meteorological Office and the University of Iceland, 20 minutes to one hour before the start of the eruption of volcano Hekla, February 26, 2000, also helped to strengthen confidence in the significance of the ongoing development in research and technology. Earlier seismologists at the University of Edinburgh and at the Icelandic Meteorological Office had also issued a short-term warning to the National Civil Defence of Iceland about a magnitude 5 earthquake at the western end of the SISZ.

An early warning and information system is in build-up in Iceland

The scientific and technological progress reported above laid the foundation to the build-up of an early warning and information system in Iceland, based at the Icelandic Meteorological Office, but with cooperational and cooperative links with other especially concerned scientist as well as National Civil Defence of Iceland and elsewhere. This system is meant to incorporate all observations in real-time and all available knowledge to mitigate risk, either by hazard assessment and pre-earthquake (pre-eruption) warnings or by nowcasting or post-earthquake service.

The need for Europe in Iceland, the need of the "Iceland Natural Laboratory" for Europe

With the PREPARED projects European scientific abilities and know-how are utilized in applying results of the recent scientific achievements and the enormous earthquake experience in Iceland for developing improved hazard assessments and improved warning algorithms. Europe is needed for this and the results will be put into practice in performing better building codes and early warnings.

Iceland is the test area for a project which has much wider dimensions. In the project scientists from 14 research institutes in 7 European countries unite hands in making use of the geological facilities of the "Iceland Natural Laboratory", and the unique data which have been collected, especially in relation to the two magnitude 6.6 earthquakes in the South Iceland seismic zone in June last year.

By participation in the work in Iceland, European earth sciences and engineering seismology are gaining experience in developing risk mitigating technology that can be applied anywhere else. The "Iceland Natural Laboratory" is a significant European basis for a generic progress in earth- and risk-mitigating sciences.

Community added value, support to EU policies

The project contributes significantly to the EU projects in mitigating risks in natural hazards, especially seismic hazards. Many ongoing EU projects in this field will gain from the progress of the PREPARED projects, as well as PREPARED will gain from results of many significant EU projects in this field during recent years. Among ongoing EU projects which will contribute to and be helped by the PREPARED project, is the ongoing SMSITES infrastructure project (Programme: Support to research infrastructures) lead by University of Edinburgh at the Húsavík fault in North Iceland and the ongoing RETINA, lead by Mécanique Appliquée et Sciences de l'Environnement in France (ACRI), aiming towards natural hazards mitigation related to 3 areas, the Azores, the Alps and the Hengill volcanic area in South Iceland. Both of these projects were encouraged by the results of the PRENLAB projects. Now both of these projects will render new observations that will be applied in the PREPARED project.

Global monitoring for environment and security (GMES)

GMES is a huge project under way in preparation in the 6th framework programme of the European Commission. Here of course the watching of earthquakes and volcanic eruptions is a significant part.

The PREPARED project with its related Icelandic Early warning and information system, where the results of PREPARED will be introduced, will be a significant contribution to the build-up and development of GMES.

C4 Contribution to Community social objectives

Information of what ground motions can be expected at various places in populated areas is socially and economically significant. Where will the faults rupture the surface and when, is of huge significance in any earthquake prone country.

Of course both the exact location of the most destruction, the severity of the destruction and at last the time are all matters of:
A gradual approach of knowledge and understanding.
A gradual approach to better probabilistic and time dependent hazard assessments, to prewarnings and nowcasting.
A gradual approach to improved risk mitigation technology.

The social and economic impact of a destructive earthquake or the knowledge that destructive earthquakes are to be expected is enormous and can be of such an extent to break up communities.

It is sometimes claimed that it is better not to know. But such knowledge cannot be hidden forever. It is the experience in Iceland that education about possible hazard impacts and knowledge about ongoing research towards risk mitigation helps people in earthquake prone areas to face the dangers and thus increases the quality of life.

Knowledge of what can be expected leads to direct precautions in where and how man-made structures are built, leads to strengthening or removal of existing vulnerable buildings. It implies various technical and social precautions and preparedness that can mitigate the impact of earthquake hazards in various ways.

The PREPARED project is economically and socially important for Iceland. But the experience gained here and the European cooperation in the project will transfer the technology and methods to be applied in other earthquake prone areas of Europe and be thus economically, socially as well as scientifically beneficial in a wide area.

The faith that people and authorities in Iceland have for earthquake prediction research efforts, and related actions of preparedness have been expressed in providing funds for building and operating high quality permanent seismic network, for building an early warning and information system, for supporting participation in European earthquake prediction research projects. This is a measure of the enormous economic and social impact that such a research can have as well as the applications of this knowledge that we propose in the PREPARED project.

C5 Project management

The Icelandic Meteorological Office, Department of Geophysics (IMOR) is the coordinator of PREPARED as in the seismic risk projects PRENLAB and PRENLAB-2 of the 4th framework programme. Ragnar Stefánsson will be the scientific leader as in these two aforementioned projects. Bardi Thorkelsson, at the same institution will have a significant role in the coordination, especially as concerns administrative and financial questions, organizing of meetings and of reporting.

It is also significant for the management of PREPARED that the coordinator, IMOR, is also the main end user of the project. It will introduce all new and tested applications, like hazard assessments and warning algorithms into the Early warning and information system (EWIS) to be a part of its operation. The coordinator, which has also formal duties for hazard assessments and warnings, will directly or through EWIS introduce the new knowledge acquired by PREPARED to the civil protection and to the authorities.

The coordinator organizes meetings and workshops, a kick-off meeting and two annual meetings as described in B6. These meetings will discuss the progress of the project on basis of reports that will be presented to the consortium before the meeting.

As described in B6 a significant feature of the project is that the 19 defined workpackages of PREPARED are organized in 5 clusters, of related and complementary activity. These cluster packages act like discussion forums and have the role of merging together results of multidisciplinary approaches towards end results applicable for risk mitigation. At the regular meetings these cluster packages will organize special sessions for discussing progress and common approaches.

Besides presenting and discussing progress and projections of work at regular meetings and in annual reports a PREPARED website will be maintained by the coordinator. Pre-meeting reports will be published there as well as the annual reports.

The regular reports of the consortium will be open to the members and to EU officials.

Quality assurance measures of deliverables will be performed by the scientifically strong PREPARED consortium on basis of written reports or website publications. As all the knowledge and algorithms produced in PREPARED will be implemented in the Early warning and information system (EWIS), the coordinator will request very strict quality assurance measures by the consortium as well as by the operators of EWIS. Testing of significance of results and other quality assurance measures will be requested from those who deliver results, to be discussed openly in the consortium.

It is expected that many of the results of PREPARED will be published in peer-reviewed international high quality scientific magazines.

C6 Description of the consortium

The consortium is a broad-based group of 14 multidisciplinary research institutes from 7 European countries, most of whom were also members of the preceding seismic risk projects, PRENLAB and PRENLAB-2. Through cooperation in these and other projects, the group constitutes a scientifically strong consortium for carrying out the research proposed.

The coordinator of PREPARED was also coordinator of the PRENLAB projects. He and his institute are also the main end users of the results, as IMOR.DG carries risk mitigating, warning and information responsibilities in Iceland. IMOR.DG develops and operates the Early warning and information system (EWIS), where the results of PREPARED will be implemented.

Iceland as a "natural laboratory" for earthquake prediction research is a facility of great importance for European earth sciences, and a unique venue for developing methods for mitigating seismic and volcanic risk. At the same time, Iceland needs high level European skills and know-how for seismic risk problem solving.

No.	Partner Name	Expertise	Role in Consortium
P1 IS	IMOR.DG: Icelandic Meteorological Office, Department of Geophysics.	Geophysical research. Seismic, continuous-GPS, and strainmeter monitoring.	Project coordination, earthquake source modeling, earthquake fault mapping, hazard assessment and warnings.
P2 SE	UUPP.DGEO: Uppsala University, Department of Earth Sciences.	Microearthquake source and location research, local-earthquake tomography, seismological monitoring.	Stress-tensor modeling from microearthquake source analysis. Development of short-term earthquake warning algorithms. Multiparameter seismic analysis.
P3 UK	UEDIN.DG: University of Edinburgh, Department of Geology and Geophysics.	Development of seismic shear-wave-splitting techniques to monitor crustal stress.	Analysis of stress-induced shear-wave splitting variations, stress forecasts.
P4 IS	NVI: Nordic Volcanological Institute.	Volcanic processes research, crustal deformation.	Long- and short-term modeling of crustal deformation using GPS, INSAR and strainmeter signals, surface-fault mapping.
P5 NO	UIB: University of Bergen, Geological Institute.	Tectonics and structural geology, fluid-flow and pressure in the crust.	Modeling of hydrological variations.
P6 IS	SIUI: Science Institute, University of Iceland.	Geoscientifical research, crustal movements, volcano studies.	Interpretation of radon data, radon warning algorithm, mapping of surface fractures.
P7 F	CNRS-UPMC: Centre National de la Recherche Scientifique, Université Pierre et Marie Curie.	Tectonics and structural geology, stress-field modeling.	Fault mapping and numerical modeling of fault-slip and earthquake-mechanism data.
P8 IT	UNIBO.DF: University of Bologna, Department of Physics.	Physical and mathematical modeling of geodynamical processes, fracture analysis.	Development of crack-models, dynamic modeling of fault interactions.
P9 D	GFZ: GeoForschungsZentrum Potsdam.	Stress-field studies, hazard assessment, disaster research.	Stress field modeling, hazard analysis.
P10 F	CNRS-Toulouse: Centre National de la Recherche Scientifique-Toulouse, Group de Recherche en Géodésie Spatiale.	Geophysical application of space geodesy, INSAR.	Modeling of INSAR data, stress-field modeling.
P11 IT	UNIVTS-DST: University of Trieste, Department of Earth Sciences.	Seismological source studies and wave	Strong motion modeling, slip distribution, hazard assessment.

		propagation, strong motion.	
P12 D	CAU: University of Kiel, Department of Geophysics.	Statistical geophysics/geo-informatics.	Pattern search in seismic data for long-term premonitory changes.
P13 CH	WAMPERR: World Agency of Planetary Monitoring and Earthquake Risk Reduction.	Monitoring geospheres for natural and anthropogenic disasters, risk assessment.	Search for precursory signals: variation in seismicity-rate and b-value.
P14 IS	ERIUI: Engineering Research Institute, University of Iceland.	Research in engineering seismology, strong-motion monitoring, hazard assessment.	Strong-motion analysis, hazard analysis.

C7 Description of the participants

1. Department of Geophysics, Icelandic Meteorological Office, Reykjavík, Iceland (IMOR)

IMOR with its 110 staff members covers a wide range of scientific disciplines in meteorology and geophysics. In the Department of Geophysics, 14 persons are currently devoted to work on seismology and related fields. Of these two are technicians, the others are scientists in seismology, geodesy, geophysics and geology.

The main duties of the Department of Geophysics are to monitor earthquakes and earthquake related changes and research based on instrumental as well as historical earthquake data. It operates the Icelandic national seismic network (SIL-network) which currently consists of 42, 3-component stations and a real-time evaluation system in Reykjavík. An alert system watching the seismic activity for different parts of the country is in automatic operation in the Department. The continuous monitoring of 7 borehole strainmeters is also included in the system, as well as of 2 gravimeters. Since 1999 11 continuously recording GPS stations have been installed in SW Iceland and several more will be added in the near future.

The research policy of the Department is focussed towards reducing seismic risk. It covers everything from general hazard assessment to the development of technology for short-term warnings alerts. The seismic system with its alert facilities and the strainmeter system is also significant for watching volcanoes and thus the Department is contributing significantly to volcanic research too, and to reducing volcanic risk. The Department has lead several multinational research projects in Iceland.

The Department led the Nordic SIL-project during 1988-1995, and the EU-funded PRENLAB and PRENLAB-2 projects during 1996-2000. It organized the XXV General Assembly of the European Seismological Commission in Reykjavík, September 9-14, 1996, in collaboration with the Ministry for the Environment and the University of Iceland. The Assembly was attended by 450 scientists in the fields of seismology, geophysics, geology, volcanology, and engineering.

Qualifications of key personnel:

Ragnar Stefánsson Born: 14/08/1938 Nationality: Icelandic

1961	**Fil. kand., mathematics and physics, University of Uppsala, Sweden.**
1965	Fil. lic. (M.Sc.), geophysics with seismology, University of Uppsala, Sweden.
1966	Fil.lic. (Ph.D), seismology, University of Uppsala, Sweden
1966-present: Head, Department of Geophysics, Icelandic Meteorological Office. Experience and expertise: Leading seismology research, monitoring, service and related geophysical work in the Department of Geophysics since 1966. This involves a wide area of seismology including hazards assessments, earthquake prediction research, build-up of a state-of-the-art acquisition and evaluation system and an attached alert system and early warning procedures. Other EC-projects: Coordinator of the seismic risk projects, PRENLAB (1996-1998) and PRENLAB-2 (1998-2000). Contractor in the projects SMSITES (2000-2002) and RETINA (2001-2005).	

Páll Halldórsson Born: 04/08/1950 Nationality: Icelandic

1979	Diplom, physics, University of Göttingen, Germany
1979-present Research scientist, Icelandic Meteorological Office. **1998-present: Deputy Head, Department of Geophysics, Icelandic Meteorological Office. Experience and expertise: He is responsible for hazard assessment at the Department of Geophysics. He is now working on a database for early warning of geological hazards.**	

Kristín S. Vogfjörð Born: 24/04/1956 Nationality: Icelandic

1982	**B.S., geophysics, University of Iceland, Reykjavík, Iceland.**
1986	**M.S., geophysics, Penn State University, University Park, Pennsylvania, USA**
1991	**Ph.D, geophysics, Penn State University, University Park, Pennsylvania, USA**
1991-1994: Postdoctoral research associate, Department of Geoscience, Penn State University, University Park, Pennsylvania, USA 1994-1997: Postdoctoral research associate, Department of Geoscience, Princeton University, Princeton, New Jersey, USA 1998-2000: Senior geophysicist, National Energy Authority, Reykjavík, Iceland. 2000-present: Research scientist, Department of Geophysics, Icelandic Meteorological Office. Experience and expertise: Her expertise is in regional seismic wave propagation, data analysis and modelling. In addition she has extensive experience in conducting seismic surveys in the field. At the Icelandic Meteorological Office she is responsible for maintaining the seismological analysis software for earthquake source modelling and for mapping of active faults with relative locations of earthquakes.	

Bardi Thorkelsson Born:26/04/52 Nationality: Icelandic

1989	B.S., geology, University of Iceland
1978-1989: Assistant, Department of Geophysics, Icelandic Meteorological Office. 1989-present: Scientist, Department of Geophysics, Icelandic Meteorological Office. Experience and expertise: Measurements and evaluation of atmospheric ozone. Administrative and economic questions. Publication work. Organizer of several workshops and meetings.General secretary of the ESC General Assembly in Iceland 1996. Financial arrangements for the PRENLAB and PRENLAB-2 projects.	

Gunnar B. Gudmundsson Born:12/11/1955 Nationality: Icelandic

1986	B.S., geophysics, University of Iceland.
1985-1986: Assistant, Department of Geophysics, Icelandic Meteorological Office. 1986-present: Scientist, Department of Geophysics, Icelandic Meteorological Office. Experience and expertise: Development, visualizing, crustal processes, organizer and participant in several OBS experiments around Iceland.	

Erik Sturkell Born: 22/06/1962 Nationality: Swedish

1988	Gescience program (160 p), Stockholm University, Sweden.
1991	M.Sc., geoscience, Stockholm University, Sweden.
1994	Fil.lic., geology, Stockholm University, Sweden.
1998	Ph.D., general and historical geology, Stockholm University, Sweden.

1991-1993: Research fellow, Nordic Volcanological Institute. 1998-2000: Postdoctoral research fellow, Nordic Volcanological Institute. 2000-present: Research scientist, Department of Geophysics, Icelandic Meteorological Office. Experience and expertise: An extensive survey of the Ordovician marine impact structure in Lockne, Sweden, which includes geological mapping, gravity, magnetometry and geochemical methods. Work on crustal deformation at many locations in Iceland using GPS measurements. Monitoring of volcanoes using GPS measurements and tilt measurements.

Bibliography of related publications of institution:

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Vogfjörð, K.S. & C.A. Langston 1996. Characteristics of short-period wave propagation in regions of Fennoscandia with emphasis on Lg. *Bull. Seism. Soc. Am.* 86, 1873-1895.

Vogfjörð, K.S. & S.Th. Rögnvaldsson 2001. Identification and modelling of secondary phases in short-period seismograms from local earthquakes in the South Iceland seismic zone. *Geophys. J. Int.*, accepted with revisions.

2. Department of Earth Sciences, Uppsala University, Uppsala, Sweden (UU)

The Uppsala seismology group consist of staff members of both the Section of Solid Earth Physics and the Section of Seismology at the Department of Earth Sciences Uppsala University. These sections did constitute the former Department of Geophysics (with about 35 academic staff) prior to the merge into the new institute of Earth Sciences with about 200 employees.

The seismology group conducts research in a number of different fields such as large- and micro-earthquake source studies, earthquake fault mapping, local earthquake tomography, seismicity studies and seismic hazard assessment. Members of the group participated in the design of the seismological network in Iceland (the SIL network) and the group is responsible for the Swedish seismological network which is now being modernized with 38 new digital stations using the SIL technology.

Qualifications of key personnel:

Reynir Bödvarsson Born: 02/12/50 Nationality: Icelandic

1977-1976	Electrical engineering at New Mexico Institute of Mining and Technology, Soccoro, New Mexico and North Carolina State University, Raleigh, North Carolina, USA.
1977-1980	Computer Science at University of Uppsala, Sweden.
1980-present: Principal investigator for several national and international research projects at Uppsala University. Contractor in four EU projects within the 4th and 5th framework programme. 1998-present: Responsible for design and construction of the new Swedish National Seismic Network (SNSN). 2000-present: Manager of the Swedish National Seismic Network operating 38 broad-band seismic stations.	

Ragnar Slunga Born 10/07/43 Nationality: Swedish

1964-1968	University education 1964-1968 at the Royal Institute of Technology (KTH) in Stockholm (physics and mathematics).
Since 1968 working at the Swedish Defence Research Institute in the fields of seismology and hydroacoustics. Since 1989 part time professor in tectonophysics at the Uppsala University. Since 1978 most of the work has been in the use of microearthquakes. The original methods I have developed includes automatic fault plane solutions based on both spectral amplitudes and first motions, high accuracy absolute and relative locations based on correlation of similar waveforms, use of both P- and T-axes when inferring the horizontal stresses involved in a microearthquake source, use of nonunique fault plane solutions for rock stress tensor estimates and including instability into the inversion, estimate of the amount of aseismic fault slip ("creep") based on the spatial and temporal distribution of the microearthquakes etc. In March 2000 I implemented a preliminar earthquake warning algorithm ("SlungaWarning") into the routine analysis at the Icelandic microearthquake analysis. At present 50% professor at the Uppsala University working with microearthquakes and 50% at the Swedish Defence Research Institute working with hydroacoustics.	

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Rögnvaldsson, S.Th. and R. Slunga 1993. Routine fault plane solutions for local and regional networks. *Bull. Seism. Soc. Am*. 83, 1232-1247.

Rögnvaldsson, S.Th. and R. Slunga 1994. Single and joint fault plane solutions for microearthquakes in South Iceland. *Tectonophysics* 273, 73-86.

Rögnvaldsson, S.Th., Á. Gudmundsson and R. Slunga 1998. Seismotectonic analysis of the Tjörnes fracture zone, an active transform fault in North Iceland. *J. Geophys. Res*. 103, 30117-30129.

Slunga, R., S.Th. Rögnvaldsson and R. Bödvarsson 1995. Absolute and relative location of similar events. *Geophys. J. Int.* 123, 409-419.

3. Department of Geology and Geophysics, University of Edinburgh, Edinburgh, United Kingdom (UEDIN)

UEDIN has about 40 academic staff (including some 17 geophysicists), 40 Research Fellows, 90 Postgraduate Students, and 35 Support Staff. It is the largest earth science department amongst UK universities. UEDIN has very extensive computing equipment and data analysis packages for both academic geology and geophysics, as well as for exploration seismology. It has the highest UK ranking as a university research institute.

Experience relevant to this project:

The Department of Geology and Geophysics has participated in well over 10 EC funded earth-science projects including the EC PRENLAB-1&2 Projects 1996-1998, 1998-2000, and is co-ordinator of the EC-funded SMSITES Project (2000-2002), which are directly relevant and form the basis and background for this present proposal.

Qualifications of key personnel:

Stuart Crampin Born: 22/10/1935 Nationality: British

1959	BSc mathematics, University of London
1965	PhD geophysics, University of Cambridge..
1978	ScD. publications in geophysics, Uniersity of Cambridge

Career: 1986-1992 Deputy Chief Scientist (Individual Merit), British Geol.Survey; 1992-1996 Prof. of Seismic Anisotropy, Dept. of Geol. and Geophys., Edinburgh Univ.; 1996- Hon. Prof. of Seismic Anisotropy, Edinburgh Univ., engaged on contracts for EC and oil companies, etc. Pioneered many aspects of seismic azimuthal anisotropy in over 220 refereed research papers. Experience and expertise: Developed with Sergei Zatsepin the APE model for rock deformation; interested in apply APE-modelling to earthquake forecasting, hydrocarbon recovery, and other implications of cracked crust as a critical system. Partner: EC PRENLAB-1&2 Projects, successfully stress-forecast an M=5 earthquake. Co-ordinator current EC SMSITES Project.

Sebastien Chastin

1989	Baccalauréat Sciences Serie D, Marseille
1991	D.U.T. Mesures Physiques, Marseille
1992	Licence de Physique, Marseille Luminy
1994	Maitrise de Physique, ERASMUS project Marseille Luminy-Sussex University
1998	PhD Low temperature condensed matter, University of Sussex

Career: Research Assistant Advanced Signal Processing Laboratory, New Castle upon Tyne Polytechnic, 1991; Post-Doctoral Fellowship, British Antarctic Survey overland Seismic Group, 5 month in deep field Antarctica. 1999 Research Fellow, Mars Climate Orbiter and Galileo space missions, NASA-Oxford University. 2000 Research Fellow and Scientific Manager of EC Project SMSITES, Dept.of Geology and Geophysics, University of Edinburgh.

Bibliography of related publications of institution:

Crampin, S., 1999a. Stress-forecasting earthquakes. *Seism. Res. Lett.* 70, 291-293.

Crampin, S., 1999b. Calculable fluid-rock interactions, *J. Geol. Soc.* 156**,** 501-514.

Crampin, S., 1999c. A successful stress-forecast: an addendum to "Stress-forecasting: a viable alternative to earthquake prediction in a dynamic Earth", *Trans. R. Soc. Edin., Earth Sci.* 89**,** 231.

Crampin, S., T. Volti, and R. Stefánsson 1999. A successfully stress-forecast earthquake, *Geophys. J. Int.* 138**,** F1-F5.

Crampin, S., 2000a. The potential of shear-wave splitting in a stress-sensitive compliant crust: a new understanding of pre-fracturing deformation from time-lapse studies. In: *Expanded Abstracts (2) of the 70th Annual International SEG Meeting,* Calgary, Canada, 1520-1523.

Crampin, S., 2000b. Shear-wave splitting in a critical self-organized crust: the New Geophysics, In: *Expanded Abstracts (2) of the 70th Annual International SEG Meeting,* Calgary, Canada,1544-1547.

Crampin, S., T. Volti and P. Jackson 2000. Developing a stress-monitoring site (SMS) near Húsavík for stress-forecasting the times and magnitudes of future large earthquakes. In: B. Thorkelsson & Yeroyanni (editors), *Destructive Earthquakes: Understanding Crustal Processes Leading to Destructive Earthquakes.* Proceedings of the Second EU-Japan Workshop on Seismic Risk, Reykjavík, Iceland, June 23-27, 1999,136-149.

Chastin, S. and S. Crampin 2001. Evidence for a critical crust. *In: Extended Abstracts of the EAGE/SEG Res. Workshop on Reservoir Rocks.*

Crampin, S. and S. Chastin 2001. Shear-wave splitting in a critical crust: II - compliant, calculable, controllable fluid-rock interactions. In: L.T. Ikelle and A. Gangi (editors), *Anisotropy 2000: Fractures converted waves and case studies.* Proceedings of the 9th International Workshop on Seismic Anisotropy, Cape Allen, 2000.

Crampin, S. and P. Jackson 2001. Developing a stress-monitoring site for stress-forecasting earthquakes: possible applications to mining-induced seismicity, *Proceedings of the 5th International Symposium on Rockbursts and Seismicity in Mines,* Johannesburg, South Africa, 2000,133-141.

4. Nordic Volcanological Institute, Reykjavík, Iceland (NVI)

NVI has participated in numerous international collaborative projects, such as PRENLAB and PRENLAB-II that have focussed on earthquake prediction research, using Iceland as a natural laboratory. Extensive crustal deformation studies have been conducted at the institute for over 20 years, in Iceland and elsewhere in the world, and the institute is well equipped for this kind of research. At the international level, NVI was a participant in the EVOP program established by the European Science Foundation. The idea behind this EVOP network was the selection of six European volcanoes, covering a wide spectrum of tectonic settings and eruptive styles, as Laboratory Volcanoes for co-operative international research aimed at better understanding of volcanoes and their eruptive phenomena. The ultimate aim of the project was to improve knowledge on volcanic behavior and European preparedness to face volcanic crisis in the future. Within the context of EVOP, NVI participated in collaborative studies on Furnas Volcano (Azores) and Krafla Volcano (Iceland), two of the six European Laboratory Volcanoes.

General information

NVI is a multinational organisation sponsored jointly by the Nordic countries, Denmark, Finland, Norway, Iceland and Sweden. The NVI was founded in 1974 and now has 16 employees. The institute focuses on basic research in plate tectonics and volcanology. Further information can be found at http://www.norvol.hi.is.

Qualifications of key personnel:

Freysteinn Sigmundsson **Born: 22/07/66** **Nationality: Icelandic**

1988	**B.S. in geophysics, University of Iceland**
1992	**Ph.D. in geophysics, University of Colorado, USA**
1992-present: Nordic Volcanological Institute, research geophysicist, NVI director since 1999. 1994-present: Advisor to the Icelandic Civil Defence Authorities. Experience and Expertise: Dr. Sigmundsson has an extensive background in deformation monitoring and tectonic studies using GPS, including post-glacial rebound. He is an expert on crustal deformation in sub-aerial parts of the world-oceanic rift system, Iceland and Afar. His current research is on active processes at volcanoes and in seismic zones, and crustal deformation related to volcanic and seismic activity using GPS and INSAR.	

Thóra Árnadóttir Born: 17/12/63 Nationality: Icelandic

1986	B.S. Geophysics, University of Iceland, Reykjavik, Iceland
1989	M.A. Geophysics, Princeton University, Princeton, New Jersey, USA
1993	Ph.D. Geophysics, Stanford University, California, USA
1996 - 1998	Research Associate in the Dept. of Geosciences, Princeton University, USA
1994-1995: Research Fellow in the Research School of Earth Science at Victoria University of Wellington (VUW), Wellington, New Zealand. 1996-1998: Research Associate in the Dept. of Geosciences, Princeton University, USA. 1998-2000: Research scientist at the IMO, Iceland. 2000-present: Research scientist at the NVI, Iceland. Experience and Expertise**:** Dr. Árnadóttir has a strong background in GPS measurements, data processing and modelling methods using geodetically observed surface deformation to derive their sources. She has extensive field experience collecting geodetic data (GPS, EDM, levelling and tilt). She was responsible for running and processing data from the continuous GPS network that is currently being set up in Iceland, while at IMO. Presently she is working on several research projects modelling crustal deformation in Iceland.	

Amy Elizabeth Clifton Born: 22/11/50 Nationality: American

1982	BA in geology, Central Connecticut State University, USA
1987	MA in structural geology and tectonics, Wesleyan University, USA
2000	PH.D. in structural geology and tectonics, Rutgers University, USA
1999-2000: Fulbright Fellow, Nordic Volcanological Institute, Reykjavík, Ieland. 2000-2002: NSF Postdoctoral Fellow, Nordic Volcanological Institute, Reykjavík, Iceland. Dr. Clifton has completed a Ph.D. thesis on the mechanics of oblique spreading. She has worked on extensional tectonics in both intraplate and interplate rift settings, as well as active processes at mid-ocean ridges. She has conducted extensive fieldwork, including field mapping of fractures in southwest Iceland and in the northeastern USA. Other topics studied by Dr.Clifton include evolution of fracture populations, fault interaction in oblique rift zones, the relationship between faulting and volcanism, structural controls on volcano location and eruption behavior, the use of analog models to solve structural problems and the use of remote sensing to solve structural problem.	

Rikke Pedersen **Born: 02/12/72** **Nationality: Danish**

1999	**M.Sc in geology, University of Aarhus, Denmark**
2000-present: Nordic Volcanological Institute, Research Fellow. Experience and Expertise: Rikke Pedersen has a M.Sc. in geochemical and petrological evolvement of volcanoes. She is currently working with crustal deformation related to volcanic and seismic activity using InSAR, and is an experienced user of the DIAPASON software used to form interferometric combinations of synthetic aperture radar images.	

Bibliography of related publications of institution:

Árnadóttir, Th. and K. Olsen 2000. Simulation of surface velocities and stress changes for the Ms=7.1, 1784 earthquake, Iceland. *Rit Vedurstofu Íslands* VÍ- R00003-JA03. Icelandic Meteorological Office, Research Report, Reykjavík.

Árnadóttir, Th., H. Geirsson, B.H. Bergsson and C. Völksen 2000. The Icelandic continuous GPS network – ISGPS, March 18, 1999-February 20, 2000. *Rit Vedurstofu Íslands VÍ-R00002-JA02.* Icelandic Meteorological Office, Research Report, Reykjavík.

Árnadóttir, Th., S. Thornley, F.F. Pollitz and D.J. Darby 1999. Spatial and temporal strain rate variations at the Northern Hikurangi Margin, New Zealand. *J. Geophys. Res. 104*, 4931-4944.

Árnadóttir, Th.and P. Segall 1994. The 1989 Loma Prieta earthquake imaged from inversion of geodetic data. *J. Geophys. Res. 99*, 21835-21855.

Sigmundsson, F., E. Tryggvason, M.M. Alves, J.L. Alves, K. Pálsson and H. Ólafsson 1995. Slow inflation of the Furnas volcano, Sao Miguel, Azores, suggested from initial leveling and Global Positioning System measurements. *Geophys. Res. Lett.* 22, 1681-1684

Sigmundsson, F., P. Einarsson, R. Bilham and E. Sturkell 1995. Rift-transform kinematics in south Iceland: Deformation from Global Positioning System measurements, 1986-1992. *J. Geophys. Res*. 100, 6235-6248.

Sturkell, E., F. Sigmundsson, P. Einarsson and R. Bilham 1994. Strain accumulation 1986-1992 across the Reykjanes Peninsula plate boundary, Iceland, determined from GPS measurements. *Geophys. Res. Lett. 21*, 125-128.

Vadon H. and F. Sigmundsson 1997. Crustal deformation from 1992-1995 at the Mid-Atlantic Ridge, SW Iceland, mapped by satellite radar interferometry. *Science* 275, 193-197.

Clifton, A.E. and R.W. Schlische 2001. Fracture populations on the Reykjanes Peninsula, Iceland: comparison with experimental clay models of oblique rifting. *J. Geophys. Res.*, submitted.

Clifton, A.E. and R.W. Schlische 2001. Nucleation, growth, and linkage of faults in oblique rift zones: Results from experimental clay models and implications for maximum fault size. *Geology* 29, 455-458.

5. Geological Institute, University of Bergen, Bergen, Norway (UIB)

With its around 18 000 students and more than 2 500 staff, the University of Bergen (UIB) is a medium-sized European university. The University of Bergen has a strong international reputation. In the EU's 4th and 5th framework programmes, UIB has participated in tens of contracts, many of which are still running.

The Geological Institute has an academic staff of 30 and, in addition, 20 technical and administrative staff. Currently, there are 30 post-doctoral students in temporary research positions at the GI, in addition to 35 Ph.D. students and 120 M.Sc. students. There is also an extensive undergraduate programme. Each year around 200 students pass through the GI.

The GI has a central administration and is divided into four research groups, namely: (1) Quaternary and marine geology, (2) petroleum geology, (3) tectonics and structural geology and (4) igneous petrology. Together these groups cover a wide spectrum of research in the general field of earth sciences. The GI has a long experience in dealing with fluid flow and pressure in crustal reservoirs, particularly in the oil industry and in petrology, and is currently expanding its research into fluid flow in solid rocks, focusing on the groundwater potential, the effects of fluid overpressure on seismogenic faulting and on triggering landslides, and the fluid mechanics and rock mechanics of magma reservoirs.

Qualifications of key personnel:

Ágúst Gudmundsson Born: 26/11/53 Nationality: Icelandic

1979	M.Sc. in structural geology and rock mechanics form Imperial College of Science and Technology, London
1984	Ph.D. in tectonophysics from University of London
He worked on volcanotectonics at the Nordic Volcanological Institute in Iceland (1985-1998), particularly on the mechanics of magma chambers, collapse calderas, dyke emplacement and faulting, but in 1998 he became a research professor and in 2000 a full professor in hydrogeology of solid rocks (fluid flow and overpressure in rock fractures, crustal reservoirs, seismicity etc.) at the Geological Institute of the University of Bergen where he now guides 16 MSc and PhD students. Gudmundsson has carried out fieldwork for 20 years, primarily in Iceland and Tenerife, been contractor and associated contractor in 4 EC projects and received many research grants in Iceland and Norway. Since 1983, Gudmundsson has published 60 papers in international books and journals and, since 1987, given around 90 talks (mostly with abstracts) in universities and at international conferences.	

Bibliography of related publications of institution:

Belardinelli, M.E., M. Bonafede and Á. Gudmundsson 2000. Secondary earthquake fractures generated by a strike-slip fault in the South Iceland Seismic Zone. *J. Geophys. Res.* 105, 13,613-13,629.

Gudmundsson, Á. and C. Homberg 1999. Evolution of stress fields and faulting in seismic zones. *Pure Appl. Geophys*. 154, 257-280.

Gudmundsson, Á.1999. Fluid overpressure and stress drop in fault zones. *Geophys. Res. Lett*. 26. 115-118.

Gudmundsson, Á. 2000.Dynamics of volcanic systems in Iceland: Example of tectonism and volcanism at juxtaposed hotspot and mid-ocean ridge systems. *Annual Review of Earth and Planetary Science* 28, 107-140.

Gudmundsson, Á. 2000. Active fault zones and groundwater flow. *Geophys. Res. Lett*. 27, 2993-2996.

Gudmundsson, Á. 2000. Fracture dimensions, displacements and fluid transport. *J. Struct. Geol.* 22, 1221-1231.

Gudmundsson, Á. 2001. Fluid overpressure and flow in fault zones: Field measurements and models. *Tectonophysics* 336, 183-197.

Gudmundsson, Á., S.S. Berg, K.B. Lyslo, and E. Skurtveit 2001. Fracture networks and fluid transport in active fault zones. *J. Struct. Geol*. 23, 343-353.

Gudmundsson, Á. and S.L. Brenner 2001. How hydrofractures become arrested. *Terra Nova*, in press.

6. Science Institute, University of Iceland (SIUI)

The University of Iceland is a state university with about 6700 students in 9 departments. The Department of Natural Sciences has about 800 students.

The Science Institute is a research institute of the Department of Natural Sciences, but with a separate budget. It has divisions of mathematics, physics, geophysics, geology, chemistry, and computer science.

The Geophysics Division has a staff of 15: 2 professors, 7 research scientists, 4 technical staff, and 2 research assistants. The main research fields are seismology, crustal movements, glaciology, paleomagnetism, geomagnetism, mass spectrometry, and volcano studies.

Further information can be found at http://www.raunvis.hi.is.

The Science Institute has been one of the leading institutions in geoscientific research in Iceland since its foundation in the sixties. It has participated in numerous collaborative projects, mostly on Icelandic research subjects, with Icelandic and international groups. For two decades it ran a country-wide network of analog seismographs which formed the conditions to forecast some of the major volcanic events in the country during that time. Major projects in geodesy to detect crustal movements have been conducted by the institute in co-operation with others, which is pertinent to this project. Active faults of the plate boundary have been studied by the institute for three decades. Radon as a precursor to earthquakes has been studied at the institute since 1978, originally funded by the US Geological Survey, but in the last years by the European PRENLAB project and the Icelandic Research Council (Rannís).

Qualifications of key personnel:

Páll Einarsson Born: 27/03/47 Nationality: Icelandic

1970	Vordiplom in physics from the University of Göttingen, Germany
1974	M.Phil. degree from Columbia University, New York
1975	Ph.D. degree from Columbia University, New York

Graduate research assistant, Lamont-Doherty Geological Observatory, 1970-75. Teaching assistant, Columbia University, 1974-75. Research scientist, Science Institute, University of Iceland, 1975-77. Senior research scientist, Science Institute, University of Iceland, 1977-1994 and 1997-1998. Head of the Geophysics division and member of the Board of Directors of the S.I. 1983-87. Member of the University Senate, U.I., 1986-90. Lecturer in the Department of Natural Sciences, U.I., 1975-94 and 1997-98. Professor of geophysics, U.I., 1994-97 and since 1999. Visiting scientist at Bullard Laboratories and Visiting Fellow of St. Edmunds College, Cambridge, 1998.

Bibliography of related publications of institution:

Einarsson, P. 1991. Earthquakes and present-day tectonism in Iceland. *Tectonophysics* 189, 261-279.

Einarsson, P., B. Brandsdóttir, M.T. Guðmundsson, H. Björnsson, K. Grönvold and F. Sigmundsson 1997. Center of the Iceland Hotspot experiences volcanic unrest. *Eos* 78, September 2, 369-375.

Einarsson, P. and B. Brandsdóttir 2000. Earthquakes in the Mýrdalsjökull area, Iceland, 1978-1985: Seasonal correlation and connection with volcanoes. *Jökull* 49, 59-73.

Erlendsson, P. and P. Einarsson 1996. The Hvalhnúkur Fault, a strike-slip fault mapped within the Reykjanes Peninsula oblique rift, Iceland. In: B. Thorkelsson (editor), *Seismology in Europe*. Proceedings of the XXV ESC General Assembly, Reykjavík, Iceland, September 9-14,1996. European Seismological Commission, 498-504.

Hreinsdóttir, S., P. Einarsson and F. Sigmundsson 2001. Crustal deformation at the oblique spreading Reykjanes Peninsula, SW Iceland: GPS measurements from 1993 to 1998. *J. Geophys. Res*. 106, 13803-13816.

Jónsson, S. and P. Einarsson 1996. Radon anomalies and earthquakes in the South Iceland Seismic Zone 1977-1993. In: B. Thorkelsson (editor), *Seismology in Europe*. Proceedings of the XXV ESC General Assembly, Reykjavík, Iceland, September 9-14,1996. European Seismological Commission, 247-252.

Jónsson, S., P. Einarsson and F. Sigmundsson 1997. Extension across a divergent plate boundary, the Eastern Volcanic Rift Zone, south Iceland, 1967-1994, observed with GPS and electronic distance measurements. *J. Geophys. Res.* 102, 11913-11930.

Sigmundsson, F., P. Einarsson, R. Bilham and E. Sturkell 1995. Rift-transform kinematics in south Iceland: Deformation from Global Positioning System measurements, 1986 to 1992. *J. Geophys. Res.* 100, 6235-6248.

Sigmundsson, F., P. Einarsson, S.Th. Rögnvaldsson, G.R. Foulger, K.M. Hodgkinson and G. Thorbergsson 1997. The 1994-1995 seismicity and deformation at the Hengill triple junction, Iceland: Triggering of earthquakes by minor magma injection in a zone of horizontal shear stress. *J. Geophys. Res.* 102, 15151-15161.

Sturkell, E., F. Sigmundsson, P. Einarsson and R. Bilham. Strain accumulation 1986-1992 across the Reykjanes Peninsula plate boundary, Iceland, determined from GPS measurements. *Geophys. Res. Lett.* 21, 125-128,

7. Laboratoire de Tectonique, Université Pierre et Marie Curie, Paris, France (UPMC)

The Federation is a Research Unit of CNRS (Centre National de la Recherche Scientifique) regrouping different laboratories of University Paris VI (Université Pierre et Marie Curie), Paris VII (Université Denis Diderot), University of Cergy-Pontoise, IPGP (Institut de Physique du Globe de Paris) and Museum National d'Histoire Naturelle. Presently the CEPAGE regroups five laboratories: (1) Petrography, (2) Mineralogy, (3), Palaeontology-Stratigraphy, (4) Marine Geosciences and (5) Tectonics. It includes more than 200 permanent researchers and technicians, plus non-permanent researchers and Ph D students.

In this Federation the "Laboratoire de Tectonique" (Tectonics) has a long experience in different domains of geodynamics, tectonics and structural geology: remote-sensing, marine geology, ductile tectonics, brittle tectonics, seismo-tectonics, structural morphology.

The "Sismotectonique and Tectonophysique" group is focusing on quantitative studies such as paleo- and present-stress reconstructions using fault slip-data sets and focal mechanisms of earthquakes, morpho-structural analysis, kinematic geodesy, numerical modelling.

For several years, Françoise Bergerat, Jacques Angelier and some different members of this group have carried out tectonic and seismo-tectonic studies in Iceland and in Taiwan, including fracture studies along and near major faults (strike-slip, normal and reverse types), stress tensor computations and numerical modelling. All these researches were carried out in close collaboration with other groups focusing on seismology, rock mechanics, analog modelling, etc.

Qualifications of key personnel:

Françoise Bergerat Born: 18/01/49 Nationalality: French

1966	Baccalauréat Sciences Expérimentales, Paris,
1971	Maîtrise de Géologie, Univ. P. et M. Curie, Paris
1972	DEA (M.Sc.) de Géologie Structurale, Univ. P. et M. Curie, Paris
1974	Doctorat de 3ème cycle (Ph.D.) en Géologie Structurale, Univ. P. et M. Curie, Paris
1985	Doctorat d'Etat ès Sciences
Career: Research Scientist in the CNRS in 1982, Research-Director since 1985. Head of the "Fédération de Recherche" CEPAGE since 1999. Over 80 publications in refereed International Journals. Distinctions: Bronze medal of the CNRS (France), 1986; Ernest Van den Broeck medal (Belgian Society of Geology), 1996. Involvement in some EU programmes as Associate-Contractor in PRENLAB-1 project (1996-1998). Contractor in PRENLAB-2 project (1998-2000). Contractor in SMSITES project (2000-2002).	

Jacques Angelier Born: 02/03/47 Nationality: French

1979	"Doctorat d'Etat"
Position: Professor since 1981. Head of the Research Team "Seismotectonics and Tectonophysics", former head of Dept of Geotectonics. Director of doctoral study formation "DEA" Quantitative methods and modelling of sedimentary basins". Editorial Boards in Taiwan. Presently member of scientific committee of french Polar Institute.	

Bibliography of related publications of institution:

Angelier, J., F. Bergerat, O. Dauteuil and T. Villemin 1997. Effective tension-shear relationships in extensional fissure swarms, axial rift zone of northeastern Iceland: morphological evidence. *J. Struct. Geol.* 19(5), 673-685.

Angelier, J., F. Bergerat and C. Homberg 2000. Variable coupling across weak oceanic transform fault: Flateyjarskagi, Iceland. *Terra Nova* 12, 97-101.

Bergerat, F., Á. Gudmundsson, J. Angelier and S.Th. Rögnvaldsson 1998. Seismotectonics of the central part of the South Iceland Seismic Zone. *Tectonophysics* 298, 319-335.

Bergerat. F., J. Angelier and S. Verrier 1999. Tectonic stress regimes, rift extension and transform motion: the South Iceland Seismic Zone. *Geodin. Acta* 12(5), 303-309.

Bergerat, F. and J. Angelier 2000. The South Iceland Seismic Zone: tectonic and seismotectonic analyses revealing the evolution from rifting to transform motion. *Journ. Geodynamics* 29(3-5), 211-231.

Bergerat, F., J. Angelier and C. Homberg 2000. Tectonic analysis of the Husavík-Flatey Fault (northern Iceland) and mechanisms of an oceanic transform zone, the Tjörnes Fracture Zone. *Tectonics* 19**(**6), 1161-1177.

Bergerat, F. and J. Angelier 2001. Mécanismes des failles des séismes des 17 et 21 Juin 2000 dans la Zone Sismique Sud-Islandaise d'après les traces de surface des failles d'Árnes et de l'Hestfjall. *C. R. Acad. Sc., Paris, Sciences de la terre et des Planètes* 333, 35-44.

Dauteuil, O., J. Angelier, F. Bergerat, S. Verrier and T. Villemin 2001. Deformation partitioning inside a fissure swarm of the northern Icelandic rift. *J. Struct. Geol.* 23, 1359-1372.

Gudmundsson, Á. and C. Homberg 1999. Evolution of stress fields and faulting in seismic zones. *Pure Appl. Geophys*. 154, 257-280.

Homberg, C., J.C. Hu, J. Angelier, F. Bergerat and O. Lacombe 1997. Characterization of stress perturbations near major fault zones: insights from 2D-distinct-element numerical modelling and field studies (Jura mountains). *J. Struct. Geol.* 19(5), 703-718.

8. Department of Physics, University of Bologna, Bologna, Italy (UNIBO)

The Department of Physics, University of Bologna, is divided into 8 research branches (Sections), one of which is the Section "Geophysics", with 8 professors 2 permanent researchers and several non-permanent research assistants, including PhD students and post-doctoral fellows.

Current activities
Main research fields in Solid Earth Geophysics include:
(a) Gravitation and solid earth tides: a superconductor gravimeter is inserted within an International network of observatories; this instrument is also employed to make experiments on the validation of Newton's gravitational law.
(b) Space Geodesy (GPS and VLBI) applied to monitor the deformation field in tectonically active areas in Italy and the Mediterranean.
(c) Seismic and gravimetric prospecting for studies of local structures.
(d) Advanced statistical methods applied to establish phenomenological relationships between geophysical observations and seismic and volcanic events, including precursory events.
(e) Physical modelling of Geodynamic processes, including Plate tectonics, post-glacial rebound, interaction with earth rotation.
(f) Theoretical and experimental fracture mechanics, with application to fault mechanics and dyke injection processes.
(g) Theoretical modelling of magma chambers, caldera unrest, volcanic conduits and lava flows.
(h) Modelling Tsunami generation and propagation following landslides, earthquakes and volcanic eruptions.

Qualifications of key personnel:

Maurizio Bonafede Born: 23/04/49 Nationality: Italian

1972	Degree in Physics, University of Bologna.
1974	Space Science Diploma, University College of London.
He was first appointed as professor in 1976 by the University of Ancona-Italy. Since 1983 he is permanent professor at the University of Bologna; at present, he is full professor of Geophysics at the Faculty of Sciences of the University of Bologna. He is the Coordinator of the Ph.D. curriculum in Geophysics. He was responsible of several research Units funded by the National Research Council (CNR), The Ministry of University and Research (MURST), and the European Community (R&D Program). He has been member of the Scientific Council of ING (Istituto Nazionale di Geofisica), of the Directive Council of Osservatorio Vesuviano and of the National Group for Volcanology. He has been organizer and convener of several national and international Scientific Meetings, Workshops and Schools. Research activities are focussed on the physical and mathematical modeling of geodynamic processes. In these fields Prof. Bonafede published more than 120 papers, mostly on peer-reviewed journals and contributed to the education of many young researchers up to their complete maturity and autonomy.	

Maria Elina Belardinelli Born: 30/04/62 Nationality: Italian

1990	Degree in Physics, Bologna University.
1994	PhD in Physics, Bologna University.

She got a ING fellowship and a Post-Doc fellowship for research at the Geophysical Sector of the Physics Department, University of Bologna. (1/2/94-28/2/96). Researcher at the Istituto Nazionale di Geofisica in the period1/3/96 al 28/2/98, at present she is Permanent researcher at the Department of Physics, University of Bologna. She participated in EEC Projects PRENLAB and PRENLAB2 (1996-1998 and 1998-2000). Affiliation: European Geophysical Society (EGS). Research topics focus on modeling earthquake and eruption source phenomena employing analytical and numerical methods in the framework of fracture theory and dislocation models. In these fields she wrote more than 30 papers, mainly on the following topics: Postseismic relaxation due to inelastic properties of fault and crustal rocks; Time-dependent properties of friction on fault; Dynamic and static stress changes in layered media; fault interactions and fault-volcano interactions.

Eleonora Rivalta Born: 1973 Nationality: Italian

1996	Degree in Physics, University of Bologna.
Since 1998	PhD student in Physics (curriculum in Geophysics) University of Bologna

She got a postgraduate studentship on EEC funds (Project PREERUPT 1996-1998) Research interests: Dislocation processes in layered elastic media with applications to faulting processes and ridge dynamics; analytic and numerical (boundary element) studies of stresses induced in heterogeneous media by magmatic sources; importance of rheological discontinuities.

Andrea Antonioli Born: 1970 Nationality: Italian

1996	Degree in Physics, University of Bologna.
Since 2000	PhD student in Geophysics, University of Bologna.

He got a postgraduate studentship on EEC funds (Project PRENLAB 1996-1998); then he was research assistent at ING (Istituto Nazionale di Geofisica, Rome). Research topics: Modelling of fault processes in layered media, taking into account viscoelastic constitutive relationships.

Elisa Trasatti Born: 1976 Nationality: Italian

2001	Degree in Physics, University of Bologna.

Post-graduate studentship from the University of Bologna within a GNV Project (National Group for Volcanology). Research topics: Numerical modelling (finite element method) of deformation processes related to magma sources and fault processes taking into account realistic topography and structural setting.

Bibliography of related publications of institution:

Belardinelli, M.E., M. Bonafede and Á. Gudmundsson 2000. Secondary earthquake fractures generated by a strike-slip fault in the South Iceland seismic zone. *J. Geophys. Res*. 105, 13613-13630.

Bonafede, M. 1995. Interaction between seismic and volcanic deformation: a possible interpretation of ground deformation observed at Vulcano Island (1976-84). *Terra Nova* 7, 80-86.

Bonafede, M. and M. Olivieri 1995. Displacement and gravity anomaly produced by a shallow vertical dyke in a cohesionless medium. *Geophys. J. Int*. 123, 639-652.

Bonafede, M. and S. Danesi 1997. Near-field modifications of stress induced by dyke injection at shallow depth. *Geophys. J. Int.*. 130, 433-448.

Bonafede, M. and M. Mazzanti 1998. Modelling gravity variations consistent with ground deformation in the Campi Flegrei Caldera. *J. Volcanol. Geotherm. Res*. 81, 137-157.

Bonafede, M. and E. Rivalta 1999. The tensile dislocation problem in a layered elastic medium. *Geophys. J. Int.* 136, 341-356.

Bonafede, M. and E. Rivalta 1999. On tensile cracks close to and across the interface between two layered elastic half-spaces. *Geophys. J. Int*. 138, 410-434.

Bonafede, M. and A. Neri 2000. Effects induced by an earthquake on its fault plane: a boundary element study. *Geophys. J. Int*. 141, 43-56.

Nostro, C., R.S. Stein, M. Cocco and M.E. Belardinelli 1998. Two-way coupling between Vesuvius eruptions and southern Apennines earthquakes, Italy, by elastic stress transfer. *J. Geophys. Res*. 103, 24487-24504.

Piersanti, A., G. Spada, R. Sabadini and M. Bonafede 1995. Global post-seismic deformation. *Geophys. J. Int*. 120, 544-566.

9. GeoForschungsZentrum Potsdam, Potsdam, Germany

The **GeoForschungsZentrum (GFZ)** is a non-university geoscientific research institute, founded on January 1st, 1992 on the Telegraphenberg in Potsdam. Financing is provided by the Federal Ministry of Education and Research. GFZ has a staff of about 600, out of which are 300 scientists. The annual budget is approximately Euro 35 million, about 30% are externally funded.
As the first of its kind world-wide, the GFZ combines all solid earth science fields including geodesy, geology, geophysics, mineralogy and geochemistry, in a multidisciplinary research centre. 22 sections are organised in five divisions according to the main topics of the GFZ: Kinematics and Dynamics of the Earth, Solid Earth Physics and Disaster Research, Structure and Evolution of the Lithosphere, Material Properties and Transport Processes and Rock Mechanics and Management of Drilling Projects. Research is accomplished by the use of a broad spectrum of methods and techniques, such as satellite geodesy and remote sensing, geophysical deep sounding, scientific drilling, experiments under in-situ conditions and modelling of geo-processes.
The GFZ maintains various instrument pools for field research and global measurement campaigns, a team of engineers for the development of geoscientific instruments and a group of specialists for the Task Force Earthquakes. An underlying principle is to combine the geoscientific know-how of universities and other research centres in national and international joint projects.

The **Section Earthquakes and Volcanism** is a research group (15 Scientists, 8 PhD students, 10 technicians and engineers, several students) with research focus and experience on origins of hazards, development and installation of monitoring networks and early warning systems, and training experts in seismic hazard assessment, in particular in developing countries. The group has experience with EU projects (PRENLAB 1 and 2 (ENV4-CT96-0252, ENV4-CT97-0536); BBMT 1 and 2 (EVSV-CT94-0049); EPOC-CT91/0043; IST-10536 SPIN).

Qualifications of key personnel:

Dr. rer. nat. Frank Roth Born 23/07/51: Nationality: German

1979	“Diplom” (M.Sc.) in physics, Bonn University
1984	Ph.D. in geophysics, Kiel University
1992	Habilitation in geophysics, Ruhr-University-Bochum
Leading Scientist at the GFZ Potsdam (since 1992). Work on logging in deep boreholes for tectonic stresses and earthquake-related changes in physical parameters of rock; analysis of seismicity; modelling of stress fields, e.g. at the North Anatolian fault; monitoring of elastic wave velocities at this fault zone. Contractor and Associated Contractor in European Commission funded projects (4th Work Programme). Co-ordinator in an INTAS-similar programme of the German Ministry of Education, Science, Research & Technology (1995-97). Several projects as Principal Investigator funded by the German Research Foundation (DFG) (since 1990), ongoing participation in a DFG-funded Collaborative Res. Centre (SFB). Research fellow of the Max-Planck-Society at the Institute of Geophysics, State Seismological Bureau, Beijing, China (1984).	

Bibliography of related publ. of institution:

Grecksch G., F. Roth, and H.-J. Kümpel 1999. Coseismic well level changes due to the 1992 Roermond earthquake compared to static deformation of half-space solutions. *Geophys. J. Int.* 138, 470-478.

Huber K., K. Fuchs, J. Palmer, F. Roth, B.N. Khakhaev, L. Van-Kin, L.A. Pevzner, S. Hickman, D. Moos, M.D. Zoback and D. Schmitt 1997. Analysis of televiewer measurements in the Vorotilov drillhole, Russia - first results. *Tectonophysics* 275, 261-272.

Roth F., 1988. Modeling of stress patterns along the western part of the North Anatolian Fault Zone. *Tectonophysics* 152, 215-226.

Roth F. 1989. A model for the present stress field along the Xian-shui-he Fault Belt, NW Sichuan, China. In: M.J. Berry (editor), Earthquake Hazard Assessment and Prediction, *Tectonophysics* 167, 103-115.

Roth F. 1990. Subsurface deformations in a layered elastic half-space. *Geophys. J. Int.* 103, 147-155.

Roth F. 1992. *Modellierung von Vorgängen an Verwerfungen mit Hilfe der Dislokationstheorie*. Habilitationsschrift, Ruhr-Universität Bochum.

Roth F. 1993. Deformations in a layered crust due to a system of cracks - modeling the effect of dike injections or dilatancy. *J. Geophys. Res.* 98, 4543-4551.

Roth F. 1994. New methods using dislocation theory. In: *Proceedings of the 8th IUGG and IAG International Symposium on Recent Crustal Movements (CRCM '93)*, Kobe, Japan, December 6-11, 1993, 265-274.

Roth, F. 1999. Stress changes in space and time at the South Iceland Seismic Zone – model calculations. In: *Proceedings of the Workshop on Recurrence of Great Interplate Earthquakes and Its Mechanism*, Kochi, Shikoku, Japan, January 20-21, 1999. Science and Technology Agency, Tokyo, 22-32.

Roth, F. and P. Fleckenstein 2001. Stress orientations found in NE Germany differ from the West European trend. *Terra Nova*, in press.

10. Groupe de Recherche en Géodésie Spatiale, CNRS –Toulouse, Toulouse, France (TOUL)

Role in the project

CNRS will participate in all workpackages concerning InSAR techniques and developing new coupling models using InSAR and GPS.

General information

The CNRS Toulouse group is part of the GRGS (Groupe de Recherche en Géodésie Spatiale), which has a long tradition of geophysical applications of space geodesy (SLR, DORIS, TOPEX/POSEIDON, GPS, ERS). It is one of a few laboratories in the world to combine the expertise in INSAR and GPS calculations with a geophysical background in modeling crustal deformation. It is thus in a privileged position to undertake this project.

The group includes two full-time research scientists in the French National science agency Centre National de la Recherche Scientifique (CNRS) based in Toulouse, France. We have distinct, but complementary research interests. Feigl is trained as a geodesist and Rigo as a seismologist. We both three have extensive experience with modern satellite techniques. We have participated as contractors in two previous EC projects: PRENLAB and PRENLAB-2, Earthquake prediction in a natural laboratory [Iceland], Environment and Climate 1994-1998 projects ENV4-CT96-0252 and ENV4-CT97-0536+A6, respectively. In addition, Feigl is Scientific coordinator of the EC RETINA project to begin in 2002. We are also involved as Principal Investigators on the following three projects granted free SAR data by the European Space Agency:

- **Feigl, K., A. Abdallah and F. Sigmundsson 1998. Evaluation of volcanic and seismic hazard by comparitive geophysics: interferometric analysis and tectonic interpretation of ERS SAR images in Djibouti and Iceland.**
- Feigl, K.L. and D. Massonnet 1999. Waiting for the big one: preparing to capture a large, shallow earthquake by ASAR interferometry.
- Rigo, A. et al. 1999. Seismic risk in Greece, monitoring active fault behavior in the most seismically active region in Europe by ENVISAT ASAR Interferometry.

In addition to satellite techniques, the group also performs observations in the field to provide a sense of ground truth to the geophysical modeling. We have both visited the field in the Southern Iceland seismic zone.

Kurt L. Feigl Born: 30/01/62 Dual nationality: USA and French

1985	B.S. in Geology & Geophysics summa cum laude, Yale University USA
1991	Ph.D. in geophysics, Massachusetts Institute of Technology
1985-1986: Research Technician, R/V R. D. Conrad, Lamont-Doherty Geological Observatory, USA. 1991–1992: Research Associate, Institut de Physique du Globe de Paris, FR 1992-present Research Scientist, Centre Nationale de la Recherche Scientifique (CNRS), FR Experience and Expertise**:** Research interests include geodetic measurement and numerical modeling of lithospheric deformation. Specialist in INSAR techniques.	

Alexis Rigo Born: 23/8/63; Nationality: French

1994	Ph.D. geophysics(seismotectonics), Université Pierre et Marie Curie, Paris, FR
1993-1994: Teaching Assistant, Institut de Physique du Globe de Paris, FR. 1995: Geophysical consultant, Coyne et Bellier, Paris, FR. 1995-present: Research Scientist, Centre National de la Recherche Scientifique (CNRS), FR. Experience and Expertise: Expert on continental seismotectonics.	

Bibliography of related publications of institution:

Feigl, K.L., A. Sergent and D. Jacq 1995. Estimation of an earthquake focal mechanism from a satellite radar interferogram: application to the December 4, 1992 Landers aftershock. *Geophys. Res. Lett.* 22, 1037-1048.

Feigl, K.L. and E. Dupré 1996. RNGCHN: a program to calculate displacement components from dislocations in an elastic half-space with applications for modeling geodetic measurements of crustal deformation. *Computers and Geosciences*.

Feigl, K.L., J. Gasperi, F. Sigmundsson and A. Rigo 2000. Crustal deformation near Hengill volcano, Iceland 1993-1998: coupling between volcanism and faulting inferred from elastic modeling of satellite radar interferograms. *J. Geophys. Res.* 105, 25655-25670.

Ferhat, G., K.L. Feigl and J.F. Ritz 1998. Geodetic measurement of tectonic deformation in the Southern Alps and Provence, France, 1887-1994, *Earth Plan. Sci. Lett.*

Massonnet, D. and K.L. Feigl 1995. Discriminating geophysical phenomena in satellite radar interferograms. *Geophys. Res. Lett.* 22, 1537-1540.

Massonnet, D., K.L. Feigl, H. Vadon and M. Rossi 1996. Coseismic deformation field of the M=6.7 Northridge, California earthquake of January 17, 1994 recorded by two radar satellites using interferometry. *Geophys. Res. Lett.* 23, 969-972.

Massonnet, D. and K.L. Feigl 1998. Radar interferometry and its application to changes in the Earth's surface. *Rev. Geophys, 36* (4), 441-500.

Peltzer, G., K.W. Hudnut and K.L. Feigl 1994. Analysis of surface displacement gradients using radar interferometry: New insights into the Landers earthquake. *J. Geophys. Res.* 99, 21971-21981.

Rigo, A. , and M. Cushing 1999. Topographic effects on levelling comparisons: case studies of Saint-Paul-de-Fenouillet (Eastern Pyrnees) and Arudy (Western Pyrenees), France, *C. R. Acad. Sci. Paris, Earth & Plan. Sci.* 329, 697-704.

Rigo, A. and D. Massonnet 1999. Investigating the 1996 Pyrenean earthquake (France) with SAR Interferograms heavily distorted by atmosphere. *Geophys. Res. Lett.* 26, 3217-3220.

11. Department of Earth Sciences, University of Trieste, Trieste, Italy (UNIVTS)

University of Trieste, Department of Earth Sciences (UNIVTS-DST), Italy. The UNIVTS-DST has been funded in 1995 by the merging of two former Institutes: the Institute of Geodesy and Geophysics (IGG) and the Institute of Mineralogy and Petrography (IMP). At present there are 15 faculty and 9 administrators/technicians affiliated with the Department. The UNIVTS-DST homepage address is: http://www.dst.univ.trieste.it/

The UNIVTS-DST has a strong seismology group, composed of two professors, four researchers and one highly qualified technician. At present, there are also five PhD students and several undergraduates doing research in seismology. The UNIVTS-DST seismology group is well known worldwide for many of its research topics, in particular: a) the computation of high-frequency synthetic seismograms through the modal summation method, b) tomography with body- and surface-waves data, c) studies of the seismic source, d) propagation of seismic waves in laterally heterogeneous media e) study of site effects, f) strong ground motion measurements, analysis and estimation for seismology and engineering seismology purposes, g) seismic hazard studies with an in-home developed deterministic approach, h) intermediate term earthquake prediction, i) study of the lithosphere at the contact between Europe and Africa.

The UNIVTS-DST is running a digital accelerometric network (Rete accelerometrica del Friuli) in the Friuli seismic area that produces regularly a bulletin making the data available to the scientific community. See the homepage for details. The group has successfully participated as contractor or associate contractor to many EU projects in the framework of the EPOCH, Environment, INTAS; Copernicus programmes in the last 6 years (e.g. EPOC-CT91-0042, EV5V-CT94-0513, CIPA-CT94-0238, ENV4-CT96-0255, EVR1-1999-00014 and INTAS RFBR-95-865).

Qualifications of key personnel:

Peter Suhadolc Born: 20/01/50 Nationality: Italian

1974	Doctor in Physics at the University of Trieste
1977-1978 CNR fellowship at Osservatorio Geofisico Sperimentale, Trieste. 1979-1980 Professor of Geophysics at the "Scuola di perfezionamento in fisica", University of Trieste. 1980-1983 Visiting researcher in Geophysics, Scuola Internazionale Superiore di Studi Avanzati, Trieste. 1984-1986 Assistant professor at the University of Trieste. 1987-1991 Assistant professor (tenure) at the University of Trieste. 1991 Royal Society visiting scientist at the Department of Earth Sciences, Oxford, UK 1992-1995 Professor of Geophysics at the University of Trieste. 1995- present Professor of Geophysics (tenure) at the University of Trieste. 1995- present Senior scientist, SAND Group, Abdus Salam International Centre for Theoretical Physics, Trieste 1997- present Director, Department of Earth Sciences, University of Trieste. 1992-present Secretary-General of the European Seismological Commission (ESC). 1997- present Director of the Department of Earth Sciences, University of Trieste. 2001-present Assistant secretary of the International Association of Seismology and Physics of the Earth's Interior (IASPEI)	

Bibliography of related publications of institution:

Aoudia, A., A. Sarao', B. Bukchin and P. Suhadolc 2000. The Friuli 1976 event: a reappraisal 23 years later. *Geophys. Res. Lett*. 27(4), 573-576.

Bajc, J., A. Aoudia, A. Sarao' and P. Suhadolc 2001. The 1998 Bovec-Krn mountain (Slovenia) earthquake sequence. *Geophys. Res. Lett*. 28(9), 1839-1842.

Orozova, I.M. and P. Suhadolc 1999. A deterministic-probabilistic approach for seismic hazard assessment. *Tectonophysics* 312, 191-202.

Sarao', A., S. Das and P. Suhadolc 1998. A comprehensive study of the effect of non-uniform station distribution on the inversion for seismic moment release history for a Haskell-type rupture model. *J. Seism*. 2, 1-25.

Suhadolc, P. 1978. Total durations and local magnitudes for small shocks in Friuli, Italy. *Boll. Geof. Teor. Appl.* 20, 303-312.

Suhadolc, P. and C. Chiaruttini 1987. A theoretical study of the dependence of the peak ground acceleration on source and structure parameters. In: M.O. Erdik and M.O. Toksoz (editors), *Strong Ground Motion Seismology*. Reidel, Dordrecht, 143-183.

Suhadolc, P., G.F. Panza and St. Mueller 1990. Physical properties of the lithosphere-asthenosphere system in Europe. In: R. Freeman and St. Mueller (editors), The European Geotraverse, Part 6, *Tectonophysics* 176, 123-135.

Suhadolc, P. and F. Marrara 1999. 2-D modeling of site response for microzonation purposes. In: F. Wenzel, D. Lungu and O. Novak (editors.), *Vrancea Earthquakes: Tectonics, Hazard and Risk Mitigation*. Kluwer, 123-136.

Triantafyllidis, P.A., P.M. Hatzidimitriou, N.P. Theodulidis, P. Suhadolc, C.B. Papazachos, K. Lontzetidis and K. Raptakis 1999. Site effects in the city of Thessaloniki (Greece) estimated from acceleration data and 1D local soil profiles. *Bull. Seism. Soc. Am*. 89(2), 521-537.

Zivcic, M., F. Vaccari and P. Suhadolc 2000. Seismic zoning of Slovenia based on deterministic hazard computations. *Pageoph*. 157, 171-184.

12. Department of Geophysics, University of Kiel, Kiel, Germany (CAU)

The Department of Geophysics at the University of Kiel, being part of the Institute of Geosciences, has a long history of research in geodynamics and the lithosphere. The department consists of six working groups: engineering and environmental geophysics, applied seismology, marine geophysics, comparative planetology / geodynamics, lithospheric research and statistical geophysics / geoinformatics. The latter group is headed by the proponent of this workpackage and focuses on statistical earthquake physics, non-linear processes, numerical methods and geoinformatics. It closely cooperates with the working group on lithospheric research which is headed by Prof. W. Rabbel, department director.

Qualifications of key personnel:

Christian Goltz Born: 21/01/64 Nationality: German

1983	German Abitur, Windhoek, Namibia
1991	Diplom in Geophysics, University of Kiel
1996	Doctor of Science, Kyoto University, Japan
1996-1997 Head of Data Processing, Lecturer and Scientist, Dept. of Geophysics, University of Kiel since 1998 Assistant Professor and head of the working group "Statistical Geophysics and Geoinformatics", Dept. of Geophysics, University of Kiel; main area of research: statistical physics of earthquakes.	

Bibliography of related publications of institution:

Goltz, C. 1997. *Fractal and chaotic properties of earthquakes.* Springer, Heidelberg.

Goltz, C. 2001. Decomposing spatio-temporal seismicity patterns. *Natural Hazards and Earth System Sciences* 1, 1-10.

Meissner, R. 1994 Erdbeben und Ursachen. *Physikalische Blätter* 50(2), 149-154.

Meissner, R. 1994. *Non-linear processes in earthquake prediction research - a review,* 159-168.

Meissner, R. 1996. Faults and folds, fact and fiction. *Tectonophysic*s 264, 279-293.

13. World Agency of Planetary Monitoring and Earthquake Risk Reduction, Geneva, Switzerland (WAPMERR)

WAPMERR was created for the following purposes defined in its charter. The objectives of the Agency shall be to reduce the impact of natural and anthropogenic disasters on human life and health, as well as property. The main activities of the Agency shall be: 2.1. Promoting monitoring of geospheres in order to estimate the potential for earthquakes and other natural disasters, and to detect anthropogenic ones rapidly. 2.2. Forecasting possible consequences of natural and anthropogenic *catas*trophes, developing response scenarios, and rendering assistance in the case of disasters. 2.3. Assessment and mitigation of natural and anthropogenic risks. 2.7. Evaluating the effectiveness of projects designed to reduce the impacts of disasters on *the* environment. 2.8. Training technical and scientific staff, and educating the public in fields of expertise of the Agency. 2.9. Developing guidelines and standards for levels of quality in activities where the Agency has expertise. More information can be found at http://www.wapmerr.org.

WAPMERR is a nonprofit organization with headquarters in Geneva, and branch offices in Moscow (Russia), France and Boulder (USA). Currently, the computing facilities include one Dell Precision Workstation 530, with Intel Xeon dual processors of 1.7GHz and 400MHz system bus, two PCs with Intel II and Intel III processors and a Sun workstation. Additional, modest computing power is budgeted in this proposal.

Qualifications of key personnel

Max Wyss Nationality: U.S. and Swiss

1964	Diploma, ETH Zuerich
1970	PhD., CALTECH

Professional employment: Director of WAPMERR, 2001. Wadati Professor, U. of Alaska, Fairbanks, 1991-2001. State Seismologist of Alaska, 1993-1994. U. of Colorado, Boulder, Fellow of CIRES and Prof., 1972-1991. Visiting Scientist at over 20 institutions 1970-2001.

Max Wyss has not yet been involved in a EU project. However, he has been principal investigator in about 60 projects, funded by agencies like NSF, USGS, and NASA etc. As a result of his last 3-year NSF grant, he published 13 papers in reviewed journals like JGR, GRL, GJI and BSSA, which is far more than required.

Max Wyss is one of the main experts on the question of precursory seismicity. He has published numerous articles on this subject and has been advocating more quantitative approaches to the problem than some researchers are accustomed to. As chairman of the IASPEI sub-commission on earthquake prediction, Max Wyss has conducted a campaign to evaluate the quality of earthquake prediction research worldwide. This resulted in two monographs, highly critical of the level of rigor in this field. As part of this activity, he also formulated guidelines for earthquake prediction research and for validating claims of precursors.

Alexander Koerner, who has a PhD from University of Berlin and is skilled in strain and computer mod
will work on this project.

Currently, WAPMERR is partially supporting one PhD student, **Danijel Schorlemmer**, at ETH, who is v
on a project related to the one proposed here and whose expertise may become available to this project al
addition, WAPMERR is planning to support a second student at ETH, **Jochen Woessner**, to work other r
projects. As WAPMERR ramps up its staff, during the period of this project, additional expertise relevan
this project will become available at WAPMERR.

Bibliography of related publications of institution:

Wiemer, S. and M. Wyss 1994. Seismic quiescence before the Landers (M=7.5) and Big Bear (M=6.5) 1992 earthquakes. *Bull. Seism. Soc. Am.* 84, 900-916.

Wyss, M. 1986. Seismic quiescence precursor to the 1983 (M=6.6), Hawaii, earthquake, *Bull. Seism. Soc. Am.* 76, 785-800.

Wyss, M., and R.O. Burford 1987. A predicted earthquake on the San Andreas fault, California. *Nature* 329, 323-325.

Wyss, M. and R.E. Habermann 1988. Precursory Seismic quiescence, *Pageoph*. 126, 319-332.

Wyss, M., K. Shimazaki and T. Urabe 1996. Quantitative mapping of a precursory quiescence to the Izu-Oshima 1990 (M6.5) earthquake, Japan. *Geophys. J. Int.* 127, 735-743.

Wyss, M. 1997. Nomination of precursory seismic quiescence as a significant precursor. *Pure and Applied Geophysics* 149, 79-114.

Wyss, M., R. Console, and M. Murru 1997. Seismicity rate change before the Irpinia (M=6.9) 1980 earthquake. *Bull. Seism. Soc. Am.* 87, 318-326.

Wyss, M. and A.H. Martyrosian 1998. Seismic quiescence before the M7, 1988, Spitak earthquake, Armenia, *Geophys. J. Int.*, *124*, 329-340.

Wyss, M., A. Hasegawa, S. Wiemer and N. Umino 1999. Quantitative mapping of precursory seismic quiescence before the 1989, M7.1, off-Sanriku earthquake, Japan. *Annali di Geophysica* 42, 851-869.

Wyss, M. and S. Wiemer 1999. How can one test the seismic gap hypothesis? The case of repeated ruptures in the Aleutians. *Pageoph*. 155, 259-278.

14. Engineering Research Institute, University of Iceland, Reykjavík, Iceland (ERI.UI)

It is the second largest research body within the University of Iceland. Its scope of work comprises basic and applied research covering a wide area of the engineering sciences, contract industrial research and training of students. The ERI is divided into five laboratories including the Applied Mechanics Laboratory, along with the Earthquake Engineering Research Centre, the main research activities of which are within the field of engineering seismology and earthquake engineering. The laboratory has currently an academic staff of eight and a yearly research budget of roughly 600,000 EURO (training not included). It has the responsibility of running and maintaining a nation-wide strong-motion network, as well as processing, verifying and interpreting the recorded data. Furthermore, the laboratory has been involved in projects where these data have been applied for design, hazard and risk assessment as well as risk management purposes. Since the seismicity of Iceland is high, in fact the highest in Northern Europe, this work is of great importance.

Ragnar Sigbjörnsson Born: 07/05/44 Nationality: Icelandic

1968	Graduated from University of Iceland
1971	Degree in civil and structural engineering from Technical Universty of Denmark
1974	PhD., from the Technical Universty of Denmark

Prof. Sigbjörnsson is currently the vice-chairman of the board of directors of the Engineering Research Institute and the dean of the Civil and Environmental Engineering Department at the University of Iceland. He has been heading the Applied Mechanics Laboratory since 1983 and the Earthquake Engineering Research Centre of the ERI since its establishment in 1999. Prof. Sigbjoernsson has an active research carrier in engineering seismology and earthquake engineering and currently his publication list contains more than 250 publications. He has also been a consultant on various industrial projects, including structural monitoring and data processing projects for the oil industry in the Norwegian Sector of the North Sea. He designed and supervised the implementation of the Icelandic strong-motion network.

Bibliography of related publication of institution:

Henje, J. C.-H., J.T. Snæbjörnsson, R. Sigbjörnsson and F.G. Sigtryggsdóttir 2000. Hydroelectric power plant in active tectonic environments. In: *Proceedings of the 11th World Conference on Earthquake Engineering*, New Zealand.

Ólafsson, S. and R. Sigbjörnsson 1995. Application of ARMA models to estimate earthquake ground motion and structural response. *Earthquake Engineering and Structural Dynamics* 24, 951-966.

Ólafsson, S., R. Sigbjörnsson and P. Einarsson, P. 1998. Estimation of source parameters and Q from acceleration recorded in the Vatnafjöll earthquake in South Iceland. *Bull. Seism. Soc. Am.* 88, 556-563.

Ólafsson, S. and R. Sigbjörnsson 1999. A theoretical attenuation model for earthquake-induced ground motion, *Journal of Earthquake Engineering* 3, Imperial College Press, 287-315.

Ólafsson, S., S. Remseth and R. Sigbjörnsson 2001. Stochastic models for simulation of strong ground motion in Iceland, *Earthquake Engineering and Structural Dynamics* 30(9), 1305-1331.

Sigbjörnsson, R. and S. Ólafsson 1992. Application of parametric time series models in earthquake engineering. *European Earthquake Engineering* 3, 43-49.

Sigbjörnsson, R., G.I. Baldvinsson and H. Thráinsson 1995. A stochastic simulation approach for simulation of seismic hazard maps. In: A.S. Alnashai (editor), *European Seismic Design Practice - Research and Application.* Balkema, 541-547.

Sigbjörnsson, R., G.I. Baldvinsson, H. Thráinsson, S. Ólafsson., G.Th. Garðarssdóttir and Ó. Thórarinsson 1995. On seismic hazard in Iceland - A stochastic simulation approach. In: *Proceedings of the 10th European conference on earthquake engineering,* 111-116. Balkema.

Sigbjörnsson, R., G.I. Baldvinsson and H. Thráinsson 1996. The mapping of seismic hazard using stochastic simulation and geographic information systems. In: *Proceedings of the Eleventh Conference on Earthquake Engineering*. Pergamon.

Sigbjörnsson, R., B. Bessason, T.I. Sigfússon and T. Sigfússon 1998. Earthquake risk mitigation in South Iceland. In: P. Bisch, P. Labbé and A. Pecker (editors), *Proceedings of the Eleventh European Conference on Earthquake Engineering*. Balkema, Rotterdam.

C9 Economic development and scientific and technological prospects

Dissemination, use and exploatation of results

All the work within PREPARED is aimed at producing tools and methodologies for mitigating seismic risk. The main results are end-user products for hazard assessment, and for issuing information and warnings. The most significant end users are the coordinator, the Icelandic Meteorological Office (IMOR) and the Engineering Research Institute, University of Iceland, which is also a participant in the project.

The coordinator (IMOR) has a legal responsibility to monitor and inform about earth activity, and provides warnings and information to the National Civil Defence of Iceland (AVRÍK) when volcanic and earthquake hazards occur or are expected, as well as during prolonged periods of increased risk. IMOR cooperates closely with AVRÍK in such situations, and works with AVRÍK in developing procedures and format of communicating information to local authorities and local Civil Defence committees, as well as to the public.

IMOR is also an adviser of, and provides hazard assessments to the Icelandic National Council for building standards. This council is responsible for preparing the national application documents (Later national annexes) for Eurocodes.

The Engineering Research Institute will apply the results to earthquake engineering research, and thus guarantee that the results will be easily applicable to the engineering community.

A website is maintained by the coordinator at the Meteorological Office for fast contacts, consulting and communication with other concerned scientists, as well as with the National Civil Defence and temporarily selected local civil defence groups in case of activity of local concern. The website also provides direct information to the media and to the public.This service will gradually be taken over by a new Early warning and information system (EWIS), which is in development and will be operated by the Meteorological Office. All risk mitigation end-results of the PREPARED project will be implemented in the EWIS database, to be available there for risk mitigation purposes.

The results of the projects will be disseminated through the participants, and to interested parties at different levels in different countries. There is no policy developed or discussed within the group, aiming to keep any significant results confidential. The main results of PREPARED will also be disseminated through open reports to the EC, as well as in public articles and conferences.

Strategic impact of PREPARED in scientific research

Besides end results directly applicable for hazard assessments and warning purposes, new knowledge and understanding will be disseminated to the European scientific community and to the world, through the participating scientists, their cooperators and through open reporting.

Competitiveness

It is probable that the methods developed in the project will, in many aspects, be innovative on a world-wide basis. One reason for this is the emphasis the EC Natural hazards projects has placed on earthquake prediction research, as compared for example to the USA. Another reason are the unique data sets and experiences available from Iceland, which will probably lead to significant advances in understanding the physical processes at work on the tectonic plate boundary. The results will therefore increase the competiveness of the participants involved.

Market opportunities for the participants

The results of the work in PREPARED may have possibilities on the market; the warning algorithms most probably, if kept confidential. The same applies to new discoveries about crustal and upper-mantle parameters and processes. Being a risk mitigation project however, it is most natural to provide open access to the results and the methodologies developed.

There is, as far as is known, no plan among the participants of PREPARED for marketing the methodologies or results developed within the project.

Implementation of PREPARED results and methodologies in other areas

Implementation of the results in other areas would mainly be through the main producers of the results and software, or by others using their methods to build up risk mitigating research or general research facilites.

C10 References in part B

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C8 Description of resources

The request for cost for equipment, consumables, computing and other special project costs, are kept well within limits, compared to the activity carried out as seen in the table. In all cases the partners contribute with their own computers and other necessary equipment, complemented in some cases with inexpensive additional equipment for new personnel expected to work in the project.

		Equipment	Consumables	Computing	Oth. spec. proj.	Total	
1	IMOR	3.500	13.700			**17.200**	WP1, WP2, WP2.5, WP3, WP3.1, WP4, WP4.1, WP4.2, WP4.4, WP5, WP5.1, WP5.2, WP5.3, WP5.4, WP5.5, WP6
2	UU	3.000		6.000		**9.000**	WP2, WP2.4, WP3, WP3.1, WP4, WP4.1, WP5.1
3	UEDIN		10.000	2.000		**12.000**	WP2, WP2.5
4	NVI	10.000	8.000	3.300		**21.300**	WP2, WP2.3, WP4, WP4.3, WP4.4, WP5, WP5.2
5	UIB		15.000			**15.000**	WP5, WP5.5
6	SIUI					**0**	WP3, WP3.2, WP4, WP4.3, WP4.4, WP6
7	UPMC		3.000			**3.000**	WP5, WP5.5, WP5.6
8	UNIBO	6.000	6.000			**12.000**	WP6, WP6.2
9	GFZ	2.800	2.500			**5.300**	WP6, WP6.1
10	TOUL	10.000	21.000		3.000	**34.000**	WP2, WP2.3, WP4, WP4.4, WP6, WP6.1, WP6.2
11	UNIVTS	8.000		5.000		**13.000**	WP4, WP4.2, WP5, WP5.4
12	CAU	2.500		3.300		**5.800**	WP2, WP2.1
13	WAPMERR	3.000	433		3.000	**6.433**	WP2, WP2.2
14	UI	5.711	2.635	3.075		**11.421**	WP4.2, WP5, WP5.3, WP5.4
	Total	**54.511**	**82.268**	**22.675**	**6.000**	**165.454**	