Veðurstofa Íslands
Report

Ragnar Stefánsson, Reynir Böðvarsson, Stuart Crampin, Frank Roth, Freysteinn Sigmundsson, Françoise Bergerat, Maurizio Bonafede, Kurt L. Feigl

Earthquake-prediction research in a natural laboratory - two Workprogramme

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Contents

TITLE

Earthquake Prediction Research in a Natural Laboratory – Two

Acronym: PRENLAB–2
PL971031

Chapter 2

WORK CONTENT

2.1 Objectives and goals

The overall objectives of the project are to provide knowledge about earthquakes and related processes which can be a basis for reducing seismic risk. The project aims at providing information about potential earthquake hazards that can be of value for society, engineers, city planners and civil protection.

Through a multidisciplinary cooperation of the partners of the project answers will be sought for the questions in following sections.

2.1.1 Where will a destructive earthquake occur?

A basis for answering this is a detailed mapping and modelling of faults and fault populations resulting from large historical earthquakes with geological methods, as well as a detailed and accurate mapping of active subsurface faults by seismological methods, which also provide the direction and size of individual fault slips. On basis of this the local rock stress tensor is monitored as well as interaction between closely spaced faults. Stress and strain changes are monitored by seismological methods like SWS, seismicity, multi-event stress inversion of fault plane solutions, as well as by strainmeters, GPS monitoring and SAR monitoring. Borehole measurements and seismic measurements provide rheological parameters necessary as a basis for modelling the dynamics of the seismic areas.

All this basic work has started and significant results are already available within PRENLAB for some areas. These results will be used in this project to estimate in a detailed way where aseismic or stable strain release prevails, and where stress is built up, which can release large earthquakes, and also to estimate where observed aseismic motion can lead to build-up of large stresses in adjacent areas.

2.1.2 What ground motions are to be expected?

How will ground motions caused by large earthquakes affect different sites, especially in the near-field of specific earthquakes?

The first question is what is the likely rupture process at specific earthquake sites. A significant basis for shedding light on this is an available detailed information on destruction, and on surface faults in some of the historical earthquakes. This is the most significant basis for the existing hazard assessment in Iceland. When combined with the knowledge acquired in the present prediction project about active faults and dynamics of fault processes, this historical information can be used to increase our understanding for earthquake processes at individual faults.

The second question is what is the site specific effect on the ground motion. Surface sediments are rare and thin in Iceland. Most buildings are based on bedrock or on lavas. A very significant site specific effect in Iceland is the proximity of buildings to faults, not only the faults which are a part of the earthquake faulting process, but also faults and fissures not directly involved. Another significant site specific effect is the structural inhomogeneity in the crust. A 3-D velocity structure tomography is under way in the ongoing PRENLAB project. Special geological mapping of crustal material and of fissures exposed on the surface, which are available for some communities within the seismic zones, add to the knowledge of site specific effects as well as seismic mapping of interior faults and surface amplification observed in minor earthquakes.

On the basis of likely rupture process and site specific effects, attempt will be made to create a dynamically realistic model to explain the damage and fissures observed in 2–3 of the best documented magnitude 7 earthquakes, with the purpose of using this model to predict likely effect of future earthquakes, in the terms of acceleration, velocity and displacement.

2.1.3 When will a large earthquake occur?

For long-term prediction, this question is related to, where inside, for example the South Iceland seismic zone (SISZ), will the next large earthquake occur. Also within the ongoing PRENLAB project work has started to model the earthquake related space-time behaviour of the stress field in the fault system of southern Iceland. This work is based on results from all other subparts of the project, and will gradually give a better constraint on the long-term prediction as well as on time relationships between clustered activity of large earthquakes, which often has occurred in the SISZ. Such work will continue through the present project and will be extended to other seismic zones along the plate boundary.

Precursory activity on the time scale of hours to days will be studied and the physics behind them. Foreshocks, frequently observed in historical earthquakes as well as in smaller instrumentally observed earthquakes, precursory changes in volumetric strain as well as in radon in borehole water will be included in the interdisciplinary modelling of the earthquake processes, with the aim of testing what significance they have for warnings.

Strain waves (strain transients) and migration of earthquake activity on a time scale of days to weeks will be studied. Such changes as indicated by volumetric strainmeters, by microseismicity and by time dependent shear-wave splitting signals will be analyzed. Combined use of active deformation and fault monitoring, together with observed rheological properties of the crust and fluid-rock interaction, will be an input to model the time and attenuation of stress and strain changes in the Iceland crust and rift zones. The aim is to investigate the feasibility to use observation of such changes to warn for increased probability of the triggering of earthquakes.

2.1.4 Stress map of Iceland

In the ongoing PRENLAB project information is being acquired from various sources about the direction of crustal stresses, and in some cases about the size. Crustal stresses are inferred from microearthquake source studies, from SWS in the ray paths, from borehole measurements, and from geological mapping of faults and dykes. A stress map based on these studies is a significant objective of the present proposal and will be a basis for further tectonic modelling, and a basis for monitoring stress changes.

2.1.5 Exporting the technology developed in Iceland

The objectives of the present proposal are not only limited to Iceland. Through the multinational participation in this project it is directly or indirectly linked to other projects aiming towards the same direction. This is significant for the fast realization of the common objectives.

A significant objective of the present proposal is to export its technology to other seismic risk areas. Collaboration has now been established to export the SIL system technology to one such area in Europe. This means rewriting the basic software, so it can be more easily used by other groups, and then of course to exchange technology and knowhow for further development.

2.2 Project methodology

PRENLAB-2 is a direct continuation of PRENLAB, which started March 1, 1996. The work packages which will be described in the following contain new work items which, however, are in many cases direct continuation of or based on work carried out under PRENLAB.

2.2.1 Subproject 1: Monitoring crustal processes for reducing seismic risk

Coordinator: Ragnar Stefánsson (IMOR.DG)

Subproject 1 coordinates the project and serves all the Subprojects of PRENLAB-2 by providing data from a multidisciplinary database. The data are historical seismic data as well as instrumental, strainmeter data, and data from other continuous monitoring, results from evaluations, as of active faults in the crust and of inferred stresses. It operates the the SIL acquisition and evaluation system consisting of 32 stations, borehole strainmeters at 6 sites, gravimeters and borehole thermometers and several other earthquake related geophysical data. It evaluates on a routine basis tens of thousands of earthquakes per year for epicenter, fault planes, moment magnitudes, etc. It brings together new results from all the Subprojects to become an intergrated part of the SIL automatic evaluation procedures and of the existing alert system. Subproject 1 initiates and carries through some research projects which are based on results from some or all of the research groups in this multidisciplinary project. Subproject 1 cooperates closely with all the other Subprojects, but special cooperative actions will be specified in the task sections below.

Task 1: Database development and service for other scientists. This task continues through the project. New data have to be incorporated because of geographical extension of the SIL monitoring system, as well as because of the extension of data acquisition included in the monitoring system. The SIL system will be developed for further acquisiton and evaluation of slow data, especially of hydrological data in thermal areas in and near the seismic zones. Based on ongoing research new interpretations of the multiplicity of available data will continuously be incorporated in the database information. The other participants and cooperators will be served with information from the ever growing database.

Task 2: Enhancing the basis for alerts, warnings and hazard assessments. Bring together research results from the project partners and from other scientists for identifying risk areas within the seismic zones, and to describe their properties. The questions to try to answer are:

a) Where in the seismic zones will the next large earthquake occur? How large motions are to be expected?. What fault plane(s) and what type of source time function is to be expected?. Work will be carried out to try to answer the questions above for the main earthquake risk zones. It will be based on mapping of surface and subsurface earthquake faults, on detailed knowledge of spatial variations of seismicity and stresses, and on theoretical modelling.

b) Evaluation of the possibility use information obtained on changes in the confining stress or strain changes to tell about increasing probability of earthquake triggering.

c) To evaluate the possibility of short–term prediction. An overview will be made of seismic activity preceding large earthquakes in Iceland and the characteristics of the foreshocks of different sites and events will be modelled with help of multidisciplinary information from various parts of the project.

Task 3: Modelling of near-field ground motions in catastrophic earthquakes in Iceland. Models will be constructed to predict the detailed characteristics of earthquake motion in the near–field of catastrophic earthquakes in Iceland, described in acceleration, velocity and displacements.

Task 4: Mobile stations for shear-wave splitting monitoring. In a special cooperation effort between Subprojects 1, 2 and 3 mobile SIL type network will be borrowed from UUPP.DGEO (Subproject 2) for monitoring during a few months above a swarm of earthquakes in the South Iceland seismic zone.

Task 5: Extending the alert system functions by real–time research. A scheme will be set up for utilizing in real–time the new information achieved during prolonged seismic activity to predict further evolution.

Task 6: To prepare the SIL system and the alert system for use in other risk areas. This task will be carried out in close cooperation with Subproject 2.

Requested extra personnel is 47 manmonths of scientists. It is expected that 90 manmonths of the permanent staff of the Department of Geophysics will be devoted to the 6 tasks above. This is about half of the scientific manpower. Travels to conferences, workshops and symposia for presenting results refer also to the permanent staff most involved in the tasks above as well as for the new personnel working for the project.

2.2.2 Subproject 2: Applying new methods using microearthquakes for monitoring crustal instability

Contractor: Reynir Bödvarsson (UUPP.DGEO)

The aim of this Subproject is to develop and apply new methods for analyzing microearthquakes in a general physical/rock–mechanical context. These methods will also be implemented and applied in the new seismic network in the Patras area in Greece. Data from the SIL network in Iceland, the Patras area in Greece, and data from a hydro-fracturing project in a geothermal field in northern Iceland will be used for testing the algorithms.

Task 1: Investigation and monitoring of stable/unstable fault movements. Utilizing the extensive information carried by the large amount of microearthquakes has the potential to find a rock-mechanical connection between microearthquakes during episodic activity. In principal this opens indirect possibilities to achieve knowledge about the aseismic fault slips. A special application is the monitoring of total slip on major faults. Present slip weakening models for fault slip predicts a long time of slow acceleration of the stable fault slip prior to big earthquakes. The use of the microearthquakes to detect this mostly stable slip may together with numerical models of fault behavior lead to possibilities to issue earthquake warnings when the fault slip is expected to become unstable.

Task 2: Statistical and adaptive analysis of space/time distribution of microearthquakes. The purpose of this Subproject is to systematically look for patterns in the almost continuous information about the crustal deformation available when recording the small earthquakes (ML=0).

Task 3: Investigation of variations of relative crustal velocities. In seismically active regions with dense networks of seismic stations the number and rate of microearthquakes will be high. This will allow a routine monitoring of the relative wave velocities of the P– and S–waves if careful multi-event analysis is applied to numbers of groups of similar earthquakes (events having highly similar waveforms). With a good station coverage it is possible to discriminate between effects from location difference and effects due to wave velocity changes.

Task 4: Implementation of this new methods in a second EU country with high seismic risk. Collaboration has been established between this group and the Seismological Laboratory, University of Patras, Greece. Prior to the project start a new seismic network will be established in the Patras area using SIL technology.

The results from the above tasks will be implemented into this new network. The work from our side will mainly include:

- Generalization of the automatic analysis software to be able to handle all type of focal depths and larger size ranges.
- Breaking up the seismological software in sub–functions to increase the adaptivity of the software to desirable changes.
- Simplify the interactive interfaces for starting up and operate the automatic analysis software.

2.2.3 Subproject 3: Shear–wave splitting to monitor in situ stress changes before earthquakes and eruptions

Contractor: Stuart Crampin (UEDIN.DGG)

This Subproject will interact with other Subprojects, particularly Subprojects 1, 2 and 4. The project requires access to data from the SIL network in Iceland, with the hopeful addition of several additional stations in a closely-spaced mini-SIL network. Note that an essential part of this project is responding to observed changes, such as the changes seen before the Vatnajökull eruption during the first PRENLAB project. Such rapid response will continue if changes are seen, but cannot be estimated beforehand.

Task 1: Continuous monitoring of shear–wave splitting. Continue monitoring shear-wave splitting for precursory changes before larger earthquakes, eruptions, and other changes of stress. The basic remit of this Subproject is to respond to changes if observed and analyze data for hazard estimation.

Task 2: Analysis of shear–wave splitting measurements. Investigate reasons why observed time–delays between split shear–waves in Iceland are approximately twice those usually observed elsewhere.

Task 3: Establish shear–wave splitting map of Iceland. A background map will allow changes in polarizations and time delays to be recognized before earthquakes, eruptions, and possibly strainwaves.

Task 4: Calibrate techniques and behaviour if and when changes are identified (possibly by other Subprojects). This task will only commence if changes are observed when it will have high priority (see task 1).

2.2.4 Subproject 4: Borehole monitoring of fluid–rock interaction

Contractor: Frank Roth (GFZ.DR.DBL)

The main objective is to monitor and analyze in a borehole in the South Iceland seismic zone the following geoparameters: P–wave travel time, porosity, resistivity near the borehole, stress information, crack density and crack closing/opening and to study stress related changes with time in the above geoparameters. The tasks of the project are in most cases a direct continuation of the basic borehole monitoring carried out under PRENLAB.

Task 1: Logging in borehole Nefsholt in months 3 and 6.

Task 2: Cross correlation of logs of the same type of this campaign to those from earlier campaigns, to search for changes in the rock physical parameters and the physical state of the rock around the borehole (months 4 and 7).

Task 3: Comparison of changes in logs of different type (months 4 and 7).

Task 4: Comparison of changes in logs with changes in seismicity, fault plane solutions, shear–wave splitting, gravity, borehole strainmeter readings, crustal deformation, etc., to investigate if changes found in the borehole can be related to anomalies detected with other methods and if they can be related to the prepartion of seismic activity (months 5 and 8-14).

Task 5: Forward modelling of effects of stress increase on rock around the borehole to find out if the stress changes can explain effects measured in well LL-03 (months 14-24).

2.2.5 Subproject 5: Active deformation determined from GPS and SAR

Contractor: Freysteinn Sigmundsson (NVI)

The objective is to measure ongoing crustal deformation in the South Iceland seismic zone and relate it to distribution of faults and seismicity there using two advanced geodetic techniques, Synthetic Aperture Radar (SAR) Interferometry and Global Positioning System (GPS) geodesy.

Subpart 5A: SAR interferometry study of the South Iceland seismic zone

Associated contractor: Kurt Feigl (CNRS.DTP)

A detailed study of deformation in the South Iceland seismic zone will be conducted using SAR interferometry, using images acquired by the European ERS satellites in the 1992–1997 period. We will form more than several interferograms of the seismic zone, showing the change in range from ground to satellite, that is the component of the displacement vector which points toward the satellite. The interferograms will completely cover the deformation field, allowing us to evaluate the amount of aseismic slip on faults in the seismic zone. To make this measurement, we will carefully inspect the interferograms near faults identified as active from mapping on the ground or in the seismicity catalog. The interferograms will also be used to identify the areas of highest elastic strain accumulation within the seismic zone.

Task 1: Analyze radar images and form interferograms (months 0–12).

Task 2: Interpret interferograms (months 6–24).

Subpart 5B: GPS measurements of absolute displacements

We will conduct semi–continuous GPS measurements at one site in the South Iceland seismic zone, and analyze data from this station along with data from two other continuously recording GPS stations in Iceland (west and east of the seismic zone). The data from the site within the seismic zone will also be analyzed with respect to continuously recording GPS stations far within the stable plate interiors in Greenland, America, Scandinavia, and continental Europe. Additionally, we will remeasure once (in a static mode) a network of GPS stations spanning the seismic zone, last measured in 1995. Joint analysis of all the continuous GPS data and the new static survey, will provide constraints on absolute plate movements near the seismic zone, that will be used to better understand the mechanism of faulting in the seismic zone.

Task 1: Operate semi–continuous GPS station (months 0–24).

Task 2: Measure a network of GPS stations spanning the seismic zone and analyze data from this network (months 6-12).

Task 3: Combined analyses of all GPS data (months 6-24).

Results for subparts 5A and 5B will be reported in at least two journal articles, manuscripts will be ready at latest at the end of the contract period.

2.2.6 Subproject 6: Effects of stress fields and crustal fluids on the development and sealing of seismogenic faults

Contractor: Françoise Bergerat (CNRS.TT)

The aims of this Subproject are (1) to determine the paleo- and present stress and strain fields associated with the seismogenic faults in the test areas, the South Iceland seismic zone and the

Tjörnes fracture zone, and (2) to make analytical, numerical and field studies on the formation, development and sealing of the seismogenic faults in these areas. Particular attention will be given to the concentration, transfer and release of tectonic stresses, and how rapidly the seismogenic faults are sealed, with application to the earthquake cycle in these test areas.

Task 1: Determine the paleostress fields associated with the test areas from fault–slip data.

Task 2: Reconstruct the current stress fields associated with the test areas using:

- Inversion of large sets of focal mechanisms of earthquakes.
- Seismotectonic analysis of individual faults.
- Geodetic analysis of present–day crustal displacements.

This part will be in close collaboration with participants in Subproject 1.

Task 3: Investigate the potential effects of fluid pressure on the probability of faulting, using field data from seismogenic faults and relevant data of fault-related geothermal fields, particularly in the South Iceland seismic zone.

Task 4: Make analytical and numerical (boundary–element and distinct–element) studies of the nucleation and development of the seismogenic faults and fault populations, using the boundary conditions obtained in tasks 1 and 2, in the test areas. One basic aim of this task is to understand the conditions leading to large–scale failure, and associated destructive earthquakes, in the test areas.

Task 5: Make a detailed analysis of the Tjörnes fracture zone test site and its vicinity. This study includes field mapping of the seismogenic faults and geodetic studies of the associated deformation field. The aim of this task is to determine if and where the faults in the test area are locked.

Task 6: Analyze the fracture properties of Icelandic rock in the laboratory and to make theoretical, observational and experimental studies on the sealing of seismogenic faults with application to the test areas in Iceland.

2.2.7 Subproject 7: Theoretical analysis of faulting and earthquake processes

Contractor: Maurizio Bonafede (UBLG.DF)

Subpart 7A: Ridge–fault interaction in Iceland employing crack models in heterogeneous media

The present Subproject aims at modelling the space–time evolution of the stress and strain fields generated from tectonic activity of the Mid–Atlantic Ridge in Iceland, employing geophysical (mainly seismic and geodetic) and structural data gathered within the project. The modelling will focus on studying the changes in crustal strain and stress due to ridge activity and earthquakes in the South Iceland seismic zone, in order to understand the the mechanisms of their interaction and the role of rheological properties in their time evolution.

Several studies have shown that the seismicity in Iceland (and in particular in the South Iceland seismic zone) may be related to the activity of the Mid–Atlantic Ridge according to an interaction mechanism between upwelling magma and seismogenic faults. In this interaction a major role is probably played by the boundary condition of magma overpressure, which can provide short-term changes in the deviatoric stress responsible for fault dynamics. A significant role is also to be ascribed to the enhanced (transient) rheological properties of a shallow asthenospheric layer, which concentrates stress transients inside the elastic lithosphere, acting as a stress guide. Great relevance must be also ascribed to lateral heterogeneities which may act efficiently to convert spreading motions into large deviatoric stresses.

According to the above scheme, two complementary scenarios can be envisaged: (1) magma upwelling along rift valleys constitutes the driving mechanism for stress build-up, its amplification in the brittle lithosphere and its migration along the stress guide, (2) stress release in major earthquakes in turn removes constraints hindering the further magma upwelling within the crust.

Task 1: Magma upwelling as driving mechanism for stress build-up in the elastic lithosphere.

The role of vertical heterogeneities, (discontinuities of elastic parameters) crossed by upwelling magma along rift valleys, will be studied employing crack models in layered media. Differently from dislocation models, in which the displacement discontinuity is assigned over a fracture surface, crack models provide solutions for the displacement and stress fields which take into account correct boundary conditions at the transition between magma and host rock. It seems plausible that several observations (heterogeneity of focal mechanisms, rotation of stress axes, antitethic strike-slip mechanisms, geochemical anomalies) will be correctly interpreted within this scheme. In particular it might be possible to characterize focal mechanisms diagnostic of magma upwelling beyond structural discontinuities.

Task 2: Space–time evolution of the stress field following earthquakes and episodes of magma upwelling.

In presence of rheological heterogeneities, stress diffusion and stress concentration phenomena are known to occur. Little has been done up to now to exploit the sudden stress changes provided by earthquakes and volcanic eruptions in order to infer the transient rheological properties of rocks. Seismic migration and the strain rate observed at the ground surface probably reflect these transient rheological properties. A quantitative description of these processes can be obtained employing transient constitutive relations, realistic geometries and structures, pertinent to the South Iceland seismic zone. Computations of post–seismic deformations and stress fields in Iceland will take advantage seismic migration and from geodetic data obtained by GPS measurements performed in South Iceland. The use of these data, in conjunction with information about the seismicity of this region, is expected to provide new insights on the interaction between the spreading ridge, the elastic and rheological structures, volcanic and seismic activity.

Subpart 7B: Modelling the earthquake related space–time behaviour of the stress field in the fault system of southern Iceland

Associated contractor: Frank Roth (GFZ.DR.DBL)

Task 1: Extrapolation of the stress field calculated within PRENLAB for the next years.

Task 2: Pin–pointing of stress concentrations in space and time.

Task 3: Search for a characteristic preseismic stress level.

2.3 Milestones

The tasks described in 2.2 will be conducted within the timetable shown in Figure 1. The end dates represent project milestones. At these end dates contractors present task reports to the coordinator to be distributed among the participants. Participants will present progress reports on individual ongoing tasks in each common progress report.

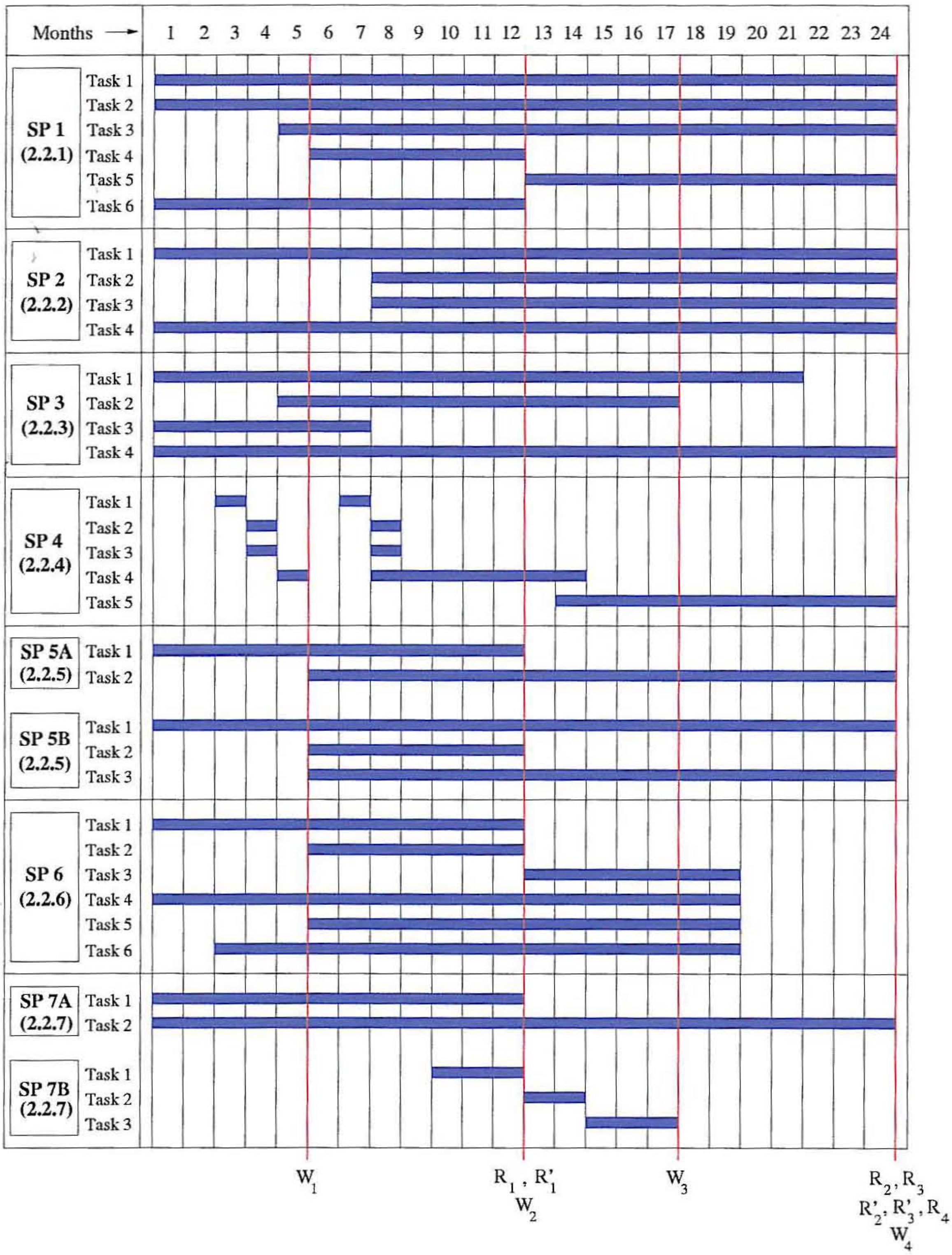

Figure 1: *Anticipated dates for research and task milestones. W_1, W_2, W_3 and W_4 are workshops, R_1 and R'_1 are first year progress report/edited report, R_2 and R'_2 are second year progress report/edited report, R_3 and R'_3 are final report/edited report and R_4 is technology implementation plan.*

Chapter 3

ROLE OF PARTICIPANTS

$\boxed{\text{Partner 1:}}$ Icelandic Meteorological Office, Department of Geophysics (IMOR.DG)

Coordinator: Ragnar Stefánsson

Coordinates PRENLAB-2. IMOR.DG will ensure that the agreed workprogramme and deadlines are followed. It will also coordinate and prepare reports to be submitted to the commission according to the contract requirements. Reports on individual tasks will be distributed among the partners and made accessible to the EC upon request. IMOR.DG will be task leader for the tasks described in 2.2.1, **Subproject 1**. It will contribute to the other Subprojects items by making geophysical data accessible. In many cases it will contribute to other projects by testing and inserting new algorithms and methods described into the on-line evaluations of the SIL system as indicated in Chapter 3. IMOR.DG will operate and extend during the project period a geophysical monitoring system and make relevant data from this accessible to other participants.

$\boxed{\text{Partner 2:}}$ University of Uppsala, Department of Geophysics (UUPP.DGEO)

Contractor: Reynir Bödvarsson

UUPP.DGEO is task leader for the work under 2.2.2, **Subproject 2**. There will be a very especially close cooperation with Subproject 1, in exchange of data and methods and in testing and applying the new methodology developed at Uppsala, and with Subproject 1 and 3 in operating mobile dense network above a cluster of seismic activity. It will implement the technical and scientific knowhow gained by the PRENLAB into a new seismic network in Patras, Greece. The main collaborator there will be subcontractor Akis Tselentis.

$\boxed{\text{Partner 3:}}$ University of Edinburgh, Department of Geology and Geophysics (UEDIN.DGG)

Contractor: Stuart Crampin

UEDIN.DGG is task leader for the work described under 2.2.3, **Subproject 3**. There will be a very close cooperation in exchange of data and methods with Subproject 1, and also with Subproject 2 in operating a dense mobile network over a cluster of activity.

$\boxed{\text{Partner 4:}}$ GeoForschungsZentrum Potsdam, Geomechanics and Management of Drilling Projects (GFZ.DR.DBL)

Contractor: Frank Roth

GFZ.DR.DBL is task leader of work described under 2.2.4, **Subproject 4** and associated to the work described under 2.2.7, **Subproject 7**, leading ***subpart 7B***. Subproject 4 is carried out by GFZ.DR.DBL in cooperation with the Icelandic Energy Authority, subcontractor Valgardur Stefánsson, and provides measuring tools and equipment. It cooperates with Subproject 1 in obtaining geophysical data.

Partner 5: Nordic Volcanological Institute (NVI)

Contractor: Freysteinn Sigmundsson

NVI leads **Subproject 5** described under 2.2.5 and ***subpart 5B*** is carried out there. The work described in ***subpart 5A*** is centralized at CNRS.DTP in special cooperation with NVI.

Partner 6: Centre National de la Recherche Scientifique – Delefation Regionale ile de France Secteur Paris B, Department de Geotectonique, Universite Pierre et Marie Curie (CNRS.TT)

Contractor: Françoise Bergerat

CNRS.TT leads the work described under 2.2.6, **Subproject 6**. This Subproject of PRENLAB-2 is a continuation of Subproject 6 of PRENLAB which was lead by Ágúst Gudmundsson at NVI. He is now on leave from NVI, but will be a subcontractor of Subproject 6. During considerable part of the period 1998–1999, subcontractor Ágúst Gudmundsson plans to stay as a visiting professor at the Université Pierre et Marie Curie in Paris to work closely with Françoise Bergerat and Jacques Angelier on this Subproject. Françoise Bergerat, Jacques Angelier and Ágúst Gudmundsson will mainly be responsible for the tasks 1–4, subcontractor Thierry Villemin for task 5 and subcontractor Philip Meredith for task 6.

Partner 7: University of Bologna, Department of Physics (UBLG.DF)

Contractor: Maurizio Bonafede

UBLG.DF leads **Subproject 7** described under 2.2.7 and ***subpart 7A*** is carried out there. It is in close cooperation and relies on observations and results from all the other Subprojects in modelling faulting and earthquake processes.

Partner 8: Centre National de la Recherche Scientifique, Delegation Regionale Midi Pyrennes Toulouse (CNRS.DTP)

Associate contractor: Kurt Feigl

CNRS.DTP is associated with **Subproject 5** described under 2.2.5 and it leads ***subpart 5A*** of it.

Tasks:		Participants:	
SP 1 (2.2.1)	Task 1 Task 2 Task 3 Task 4 Task 5 Task 6	CO:	Department of Geophysics, Icelandic Meteorological Office, Reykjavík, Iceland Ragnar Stefánsson
SP 2 (2.2.2)	Task 1 Task 2 Task 3 Task 4	CR:	Department of Geophysics, Uppsala University, Sweden Reynir Bödvarsson
SP 3 (2.2.3)	Task 1 Task 2 Task 3 Task 4	CR:	Department of Geology and Geophysics, University of Edinburgh, U.K. Stuart Crampin
SP 4 (2.2.4)	Task 1 Task 2 Task 3 Task 4 Task 5	CR:	GeoForschungsZentrum, Potsdam, Germany Frank Roth
SP 5A (2.2.5)	Task 1 Task 2	AC:	CNRS, Toulouse, France Kurt Feigl
SP 5B (2.2.5)	Task 1 Task 2 Task 3	CR:	Nordic Volcanological Institute, Reykjavík, Iceland Freysteinn Sigmundsson
SP 6 (2.2.6)	Task 1 Task 2 Task 3 Task 4 Task 5 Task 6	CR:	Université Pierre et Marie Curie, CNRS Delegation B, Paris, France Françoise Bergerat
SP 7A (2.2.7)	Task 1 Task 2	CR:	Department of Physics, University of Bologna, Italy Maurizio Bonafede
SP 7B (2.2.7)	Task 1 Task 2 Task 3	AC:	GeoForschungsZentrum, Potsdam, Germany Frank Roth

Figure 2: *Participants responsible for tasks listed in Chapter 2.*

DELIVERABLES AND WORK PLANNING/SCHEDULE

4.1 Contractor/project reviewing workshops

Contractor/project reviewing meetings are planned approximately in months 5, 12, 17, and 24 (Figure 1). These meetings will be in the forms of workshops open to the contractors, associated contractors, scientists working on the project and other invited guests and experts nominated from EC. The purpose of the meetings is to plan future work and publications, and to review the work already done. Generally speaking the purpose is to focus this multidisciplinary project towards the common goals.

The workshops are planned to coincide with European geoscience assemblies, i.e. ESC, EUG and EGS meetings, where papers resulting from the project will be presented. Besides these general meetings there will be minor meetings of participants cooperating on specific tasks.

The internet will play a significant role in the reporting/communication among the participants, through the coordinator's homepage on the World Wide Web.

4.2 Reports to the European Commission

Two 12–monthly progress reports together with edited summary reports will be submitted and published not later than 13 and 25 months respectively after the start of the project. A final report covering all the 24 months of the project period will be submitted not later than 26 months after the start of the project. A technology implementation plan will be prepared and submitted not later than 2 months after the end of the project (Figure 1).

Information about available computer software and about how to access data from databases will be distributed to a wider audience by including it in peer–reviewed papers when it is adequate. Such information will to some extent be circulated through the World Wide Web as well as information about the progress reports and how to access them. A common colour leaflet will be published to give a short overview of the project objectives and milestones.

4.3 Publications in peer-reviewed journals

All the participants will submit papers in peer-reviewed earth science journals based on obtained results. All the work topics and most of the work tasks of the planned work content will result in papers to be submitted for publication soon after finishing the tasks. It will be emphasized that papers be prepared jointly by members of different research groups involved.

4.4 Completion of work packages

The work tasks and the interconnection between these are described in Chapters 2 and 3 and Figure 1. Completion of tasks will result in reports worked out by those who cooperate on the various tasks, and in most cases in submitting papers to peer-reviewed journals. A final report will be issued containing the results of all the Subprojects. This report will focus on answering the questions posed on where, how and when large earthquakes will occur in Iceland. It will focus on methods that can be used in Iceland and elsewhere for reducing seismic risk.

Chapter 5

COMPLEMENTARY PROJECTS

This project is a direct continuation of the project *Earthquake-Prediction Research in a Natural Laboratory (PRENLAB)*, EC project, contract no. ENV4-CT96-0252. That project started March 1, 1996 and will finish its term on February 28, 1998.

This project *Earthquake-Prediction Research in a Natural Laboratory - Two (PRENLAB-2)*, is a new project with a new work content.

SCIENTIFIC PARTNERS

Partner 1
Icelandic Meteorological Office
Department of Geophysics
Bústadavegur 9
IS-150 Reykjavík
Iceland
Dr. Ragnar Stefánsson
Tel.:+354-5600600
Fax:+354-5528121
E-mail: ragnar@vedur.is

Partner 2
Uppsala University
Department of Geophysics
Villavägen 16
S-752 36 Uppsala
Sweden
Mr. Reynir Bödvarsson
Tel.: +46-18-182378
Fax: +46-18-501110
E-mail: rb@geophys.uu.se

Partner 3
University of Edinburgh
Department of Geology and Geophysics
Kings Buildings, West Mains Road
Edinburgh, EH9 3JW
United Kingdom
Professor Stuart Crampin
Tel.: +44-131-6504908
Fax: +044-131-6683184
E-mail: scrampin@ed.ac.uk

Partner 4
GeoForschungsZentrum Potsdam
Telegrafenberg A34
D-14473 Potsdam
Germany
Dr. Frank Roth
Tel.: +49-331-2881530
Fax: +49-331-2881534
E-mail: roth@gfz-potsdam.de

Partner 5
Nordic Volcanological Institute
Grensásvegur 50
IS-108 Reykjavík
Iceland
Dr. Freysteinn Sigmundsson
Tel.: +354-5254494
Fax:+354-5629767
E-mail: fs@norvol.hi.is

Partner 6
Centre National de la Recherche Scientifique
Delegation Regionale Ile de France Secteur Paris
B (C.N.R.S. - DR2)
Departement de Geotectonique
Universite Pierre et Marie Curie
4, place Jussieu
75252 - Paris CEDEX 05
Dr. Francoise Bergerat
Tel.: +33-1-4427-3443
Fax: +33-1-4427-5085
E-mail: bergerat@lgs.jussieu.r

Partner 7
Universita di Bologna
Dipartimento di Fisica
Viale Berti-Pichat 6/2
I-40127 Bologna
Italy
Professor Maurizio Bonafede
Tel.:+39-51-6305001
Fax:+39-51-6305058
E-mail: bonafede@ibogfs.df.unibo.it

Partner 8
Centre National de la Recherche Scientifique
Delegation Regionale Midi Pyrennes
UPR 234
14, Avenue Edouard Belin
F-31400 Toulouse
France
Dr. Kurt Feigl
Tel.: +33-613-32940
Fax: 33-612-53205
E-mail: feigl@medoc.cnes.fr

Earthquake-Prediction Research in a Natural Laboratory - Two

Objectives:

To provide knowledge about earthquakes and related earth processes which can be a basis for reducing seismic risk.

To respond to the increasing requests from society, city planners, engineers and rescue teams for improved knowledge about where a destructive earthquake is likely to take place, how intensive it will be, and when it is likely to occur.

To create a better understanding of the physical processes leading to earthquakes by a multidisciplinary geoscience approach.

Brief description of the research project:

The test area for the project is the the Mid-Atlantic plate boundary in Iceland, where earthquakes up to magnitude 7 occur in two transform zones. Variable strain rate in the transform zones is contolled by an interplay between mantle plume activity and the general plate divergency. The project takes advantage of the state-of-the-art technology and earthquake monitoring systems available in Iceland.

Seismological research is based on data from historical catastrophic earthquakes, instrumental earthquake data of this century and on modern microearthquake data. The microearthquake seismology includes source studies, resulting in mapping of active subsurface faults, monitoring of stable and unstable fault movements and rock stress tensor inversion. It contains studies of ray path effects such as velocity and shear-wave splitting and the stress dependency of these parameters. It contains search for patterns in time and space such as foreshocks, nucleation and migration of activity.

Exposed faults and fissures are studied in the field to reveal paleostresses, the nucleation of faults, and the effects of fluid pressure on the development of seismogenic faults.

GPS, SAR and volumetric strainmeter measurements are carried out and evaluated for monitoring ongoing deformation and strain changes in and near the seismic zones.

Borehole measurements are carried out to provide geoparameters which are of significance for earthquake modelling. Possible time variations of these are studied.

Theoretical analysis of faulting and earthquake processes, constrained by the multidisciplinary observations. This includes modelling of earthquake related changes of stress field and effects of magma upwelling for the stress build-up.

The results of the project will be of significance for enhanced hazard assessments and the alert system in Iceland. The results and technology developed will also be prepared for exporting to other earthquake prone areas. As a part of this a special collaboration has been established with the University of Patras in Greece.