International Colloquium


Chaire Gutenberg

Major Historical Earthquakes of the Rhine Graben

Interplate - Intraplate Continental Deformation

From archives to comparative seismotectonics

VOLUME OF ABSTRACTS

11, 12 and 13 May 2015

Institut de Physique du Globe of Strasbourg

Introduction

Colloquium title: Major historical earthquakes of the Rhine Graben:
Interplate - Intraplate Continental Deformation
From archives to comparative seismotectonics

11, 12 and 13 May 2015
Institut de Physique du Globe
University of Strasbourg

The colloquium focuses on seismological studies of the Rhine Graben and intraplate Europe and follows the first edition also dedicated to historical earthquakes and held in Freiburg (May 19 and 20, 2014), The topics addressed in this colloquium deal mainly with the relationships between recent seismicity, non-instrumental earthquakes and their seismotectonic characteristics. The colloquium is organised around three themes:

I. Historical earthquakes and intraplate deformation of the Rhine Graben:
Role of the background seismicity
II. Rifting and continental faulting:
Lessons learned from on - off plate boundaries
III. Seismotectonics, induced seismicity and implications
for the seismic hazard and risk

Recent large and destructive earthquakes in the Euro-Mediterranean area have changed our perception on the crustal deformation and seismic hazard assessment in active zones. The development of seismic and GPS networks, combined with InSAR data and field investigations in tectonic geomorphology along active faults provide a wealth of data on the static and dynamic processes of earthquake ruptures. Therefore, large continental faults such as the North Anatolian Fault and Dead Sea Fault represent the field of ideal natural laboratory for the understanding of the short/long–term crustal deformation.

The Rhine Graben is an active zone with low deformation rate and a complex pattern of intraplate deformation with rifting. Intraplate seismogenic structures are indicators of significant strain accumulation far from plate boundaries. Understanding the deformation in such context remains a key issue to better identify the processes controlling the occurrence of moderate and large intraplate earthquakes and estimate the associated seismic hazard.

Comparing the Rhine Graben with other rifting zones in intraplate or interplate context would help to improve our evaluation of the seismic hazard in continental Europe. The development of new approaches using seismic and GPS networks, combined with InSAR, LIDAR and field investigations in tectonic geomorphology and paleoseismology along active faults provide a wealth of data on earthquake ruptures and their return period.

Intraplate seismogenic structures are evidences of significant strain accumulation far from plate boundaries, where most of seismic energy is released. Understanding the deformation in such context remains a key issue to better identify the processes controlling the occurrence of moderate and large intraplate earthquakes and estimate the associated seismic hazard. This is the case of the Rhine Graben, confronted to a low deformation rate with a complex pattern of rifting and intraplate deformation. Comparing the Rhine Graben with similar seismotectonic domains in the world would help to improve our evaluation of the seismic hazard in intraplate Europe.

Mustapha Meghraoui
Organizing Committee
EOST - IPGS

Acknowledgements: *The colloquium is supported by the University of Strasbourg (vice-Présidence Recherche), the Cercle Gutenberg and its President Professor Pierre Braunstein, the Ecole et Observatoire des Sciences de la Terre (EOST) and its Director Prof. Frédéric Masson, the Institut de Physique du Globe of Strasbourg (IPGS) and its Director Prof. Ulrich Achauer. The colloquium organization benefited from the assistance of Parfait Nguema Edzang, Scarlett Gendrey, Anouk Duparc and Cedric Sachet (IPGS), Ghenima Begriche (EOST) and "La Cellule Congrès" (Christine Guibert and Marion Oswald) of the University of Strasbourg.*

PROGRAMME

ORAL :

Monday 11 May 2015 Chairman : Ulrich Achauer

13 :30 14 :00	Registration
14 :00 14 :30	**Opening :** Ulrich Achauer, Director of Institut de Physique du Globe of Strasbourg Paul-Antoine Hervieux, Vice-President Research Delegate, University of Strasbourg Pierre Braunstein, President Cercle Gutenberg, Membre of the Academy of Sciences
14 :30 15 :00	**The 1952 seismic sequence of the northern Upper Rhine Graben: Focal depth and clues for a larger earthquake rupture** Mustapha Meghraoui, Christophe Sira, and C. H. Rime
15:00 15:30	**Earthquake catalogue for southwestern Germany – A status report** Wolfgang Brüstle, Silke Hock, Uwe Braumann, Fee-Alexandra Rodler and Andreas Greve
15:30 16:00	Coffee Break
16:00 16:30	**Biases and fragmentations in historical EQ-records. The pre-instrumental period of systematic scientific earthquake observation in Switzerland (1878–1912)** Grolimund Remo and DonatFäh
16:30 17:00	**Coseismic vs. aseismic deformation in the Upper Rhine Graben and the case of the 1735 Gießen earthquake** Andreas Barth
17:00 17:30	**Estimation of magnitude-depth parameters based on automatic Isoseismal areas for XXth century selected earthquakes.** Antoine Schlupp
18:00 20:00	Ice Breaker

Tuesday 12 May 2015 Chairman : Thierry Camelbeeck

09 :00 09 :30	**The Earthquake Catalogue of Germany, current status and future plans** Diethelm Kaiser, Dietmar Bürk, Gernot Hartmann
09 :30 10 :00	**Earthquake catalog EKDAG V2.0: Macroseismic observations of damaging earthquakes in Southwestern Germany** Silke Beinersdorf, Jochen Schwarz and Hein Meidow
10 :00 10 :30	**Magnitude overestimation or temporal variations in the Italian seismicity of the 20th century?** Massimiliano Stucchi

10:30 11:00	Coffee Break
11:00 11:30	**A magnitude 6.6 event in the Basel region: From historical and archeological observations to risk scenarios** Donat Fäh, Clotaire Michel, Pia Hannewald, Pierino Lestuzzi, Stephan Husen
11:30 12:00	**Simulation of Mmax distributions for superdomains in stable continental regions** Kris Vanneste, Bart Vleminckx, Seth Stein & Thierry Camelbeeck
12:00 12:30	**Interpreting Seismotectonics for Seismic Hazard in Intraplate Areas: The British Isles as a Case Study** Roger M. W. Musson
12:30 14:00	Lunch

Chairman : Wolfgang Brüstle

14 :00 14 :30	**Detailed seismological studies using observations of dense seismic network: the case of the Dead Sea basin** Rami Hofstetter **fellow of Chaire Gutenberg,** Catherine Dorbath, Louis Dorbath
14 :30 15 :00	**Induced seismicity in EGS reservoir: the creep route** Jean Schmittbuhl, Olivier Lengliné, François Cornet, Nicolas Cuenot and Albert Genter
15:00 15:30	**Fluid-induced earthquakes with variable stress drop** O. Lengliné, L. Lamourette, L. Vivin, N. Cuenot and J. Schmittbuhl
15:30 16:00	Coffee Break
16:00 16:30	**Reassessment of the rifting process in the Western Corinth rift from relocated seismicity** S. Lambotte et al.
16:30 17:00	**The Byzantine walled obelisk of Istanbul and an unknown earthquake from the 10-11th century** Miklós Kázmér
17:00 17:30	**The Armedea project: Archaeology of medieval earthquakes in Europe (1000-1550 AD)** P. Forlin, C. Gerrard, D. Petley,
17:30 18:00	**Archaeoseismology, can it extend our archives?** Klaus-G. Hinzen
19:30 21:30	Dinner (Restaurant at Musée d'Art Moderne)

Wednesday 12 May 2015 Chairman : Roger Musson

09 :00 09 :30	**The Rhine rift within the frame of the Cainozoic evolution of the Alpine foreland** A. M. Celâl Şengör
09 :30 10 :00	**Paleoseismicity of Normal Faults in Active Intra-arc and Back-arc Settings: Examples from New Zealand, Mexico and Oregon**

	Rob M. Langridge and Pilar Villamor
10 :00 10 :30	**Faults and earthquake activity in northwestern Europe** Thierry Camelbeeck, Kris Vanneste, Koen Verbeeck, Koen Van Noten and Thomas Lecocq
10:30 11:00	Coffee Break
11:00 11:30	**Tectonic heritage control on intraplate strain and seismicity rates** Stephane Mazzotti and Frédéric Gueydan
11:30 12:00	**Large earthquakes in stable continental plate interiors: the need for a new paradigm** Eric Calais, Thierry Camelbeeck, and Seth Stein
12:00 12:30	**Challenges in Assessing Seismic Hazard in Intraplate Europe** Seth Stein, Angela Landgraf, Esther Hintersberger, Simon Kuebler, and Mian Liu
12:30 14:00	Lunch

Chairman : Mustapha Meghraoui

14 :00 14 :30	**The Alpine Fault: Paleoseismicity of 'le premiere faille' in New Zealand** Rob M. Langridge
14 :30 15 :00	**Systematic compilation of paleoseismic evidence in Germany and adjacent areas** Jochen Hürtgen, Thomas Spies, Jörg Schlittenhardt, and Klaus Reicherter
15:00 15:30	**Normal fault systems and associated earthquakes along the axial zone of the Apennines (Italy)** EmanueleTondi
15:30 16:00	Coffee Break
16:00 16:30	**3D Surface Displacement Rates in the Upper Rhine Graben Area from a Combination of Levelling, GNSS and InSAR** T. Fuhrmann, M. Mayer, M. Westerhaus, K. Zippelt, and B. Heck
16:30 17:00	**Fault PSHA for the Fessenheim NPP, eastern France** Christophe Clément, Thomas Chartier, Oona Scotti, Stéphane Baize, Hervé Jomard
17:00 17:30	Closure (discussion – recommendation)

POSTER

Seismic hazard estimation of induced seismicity associated with deep geothermal energy production
Thomas Spies and Jörg Schlittenhardt

Recent and future evolution of the seismic network in Alsace and in Northeastern France
Doubre, C., Bes de BercM., Wodling H., Jund H., Grunberg M., Vergne J., and Blumetritt H.

Current surface displacements observed from TerraSAR---X InSAR monitoring at local scale in the Upper Rhine Graben
Christine Heimlich, Frédéric Masson, and Cécile Doubre

Combined leveling, triangulation and survey-mode GPS data in the southern Upper Rhine Graben: A review of centennial-old data to estimate crustal deformation.
Ferhat G., M. Meghraoui and F. Masson

Magnitude-frequency distribution of induced and tectonic seismicity in the Upper Rhine Graben/Germany
Andreas Barth and Jörn Groos

Limits of tectonic geomorphology techniques in the Lower Rhine Basin
Evelyn Schürmann, Christoph Grützner, Jochen Hürtgen and Klaus Reicherter

New paleoseismological data from the Rurrand Fault, Lower Rhine Basin
Christoph Grützner, Jochen Hürtgen, Peter Fischer and Klaus Reicherter

Coseismic vs. aseismic deformation in the Upper Rhine Graben and the case of the 1735 Gießen earthquake

Andreas Barth, Karlsruhe Institute of Technology (KIT), Geophysical Institute

1) Seismic activity in the densely populated Upper Rhine Graben (URG) is an aspect in the public, political, and industrial decision making process. The spatial analysis of magnitude-frequency distributions provides valuable information about local seismicity patterns and regional seismic hazard assessment and can be used also as a proxy for coseismic deformation to explore the seismo-tectonic setting of the URG.

We combined five instrumental and one historic earthquake bulletins to obtain for the first time a consistent database for events with local magnitudes $M_L \geq 2.0$ in the whole URG and use it for the determination of magnitude frequencies. Our analysis revealed significant *b*-value variations along the URG with significant differences in earthquake magnitude distributions: Basel region (*b*=0.83), region between Mulhouse and Freiburg in the southern URG (*b*=1.42), central URG (*b*=0.93), northern URG (*b*=1.06). High *b*-values and thus a relatively low amount of high magnitude events in the Freiburg/Mulhouse region are possibly a consequence of strongly segmented, small-scale structures that are not able to accumulate high stresses.

We used the obtained magnitude-frequency distributions and representative source mechanisms for each section to determine coseismic displacement rates. A maximum horizontal displacement rate of 41 µm/a around Basel is found whereas only 8 µm/a are derived for the central and northern URG. A comparison with geodetic and geological constraints implies that the coseismic displacement rates cover less than 10% of the overall displacement rates, suggesting a high amount of aseismic deformation in the URG.

2) The Hessian depression, which is the eastern branch of the northern elongation of the URG, is a region of low seismicity in the centre of Germany. According to historic bulletins, one of larges events occurred on August 22, 1735 at the city of Gießen with a maximum intensity of V. We analysed primary historic sources as newspapers, local chronicals, and church registers to re-evaluate the earthquake source parameters. We found, that the earthquake was widely felt within a radius of perceptibility of at least 100 km. The epicentre was localised around 50 km west of Gießen in the Westerwald region, which is know for its recent low magnitude earthquake series. We determined intensities up to VI, leading to a evetnt magnitude $M_L \geq 4$ at 10-15 km depth. The re-evaluation of this outstanding seismic event shows the great importance of improved knowledge of historic seismicity in low to moderate seismic regions for regional scale hazard and deformation studies.

Magnitude-frequency distribution of induced and tectonic seismicity in the Upper Rhine Graben/Germany

Andreas Barth, Karlsruhe Institute of Technology (KIT),
Jörn Groos, KIT, now at German Aerospace Center (DLR)

Seismic activity in the densely populated Upper Rhine Graben/Germany (URG) is an important issue for the public, politics, and industry. The spatial analysis of magnitude-frequency distributions of both, tectonic and induced seismicity, provides valuable information about local seismicity pattern and seismic hazard assessment.
The URG is a NNE-SSW striking continental rift north of the Alpine mountain chain in the German-French-Swiss border region and it is one of the active seismic regions in Central Europe. Its total length is about 320 km from Basel/Switzerland in the south to Frankfurt/Germany in the north. We use *b*-value variations of the tectonic seismicity along the URG to separate four distinct sections with significant differences in earthquake magnitude distributions: the Basel region in the Swiss-France-German border region (*b*=0.83), the region between Mulhouse and Freiburg in the southern URG (*b*=1.42), the central URG (*b*=0.93), and the northern URG (*b*=1.06).
According to this separation, the geothermal power plants of Landau and Insheim are located in the transition of the central URG to its northern part. The seismic network in their surrounding detected 1.982 induced events between September 2009 and August 2013 with magnitudes as low as M_L -1.0. We analyse the *b*-value of the magnitude-frequency distribution for several periods of induced seismicity and compare it to the local tectonic activity level.
The return period of a tectonic earthquake $M_L \geq 0.0$ for an area of 10 km² - as it is affected by the geothermal power plants in Landau or Insheim - is three years. However, induced seismicity at the Landau site reveals within the four years of observation a seismic activity of 28 events per year with $M_L \geq 0.0$ (*b*=0.65), which corresponds to an increase of a factor 100 compared to the average tectonic activity. A similar estimation for the Insheim power plant results in even ten times higher rates for induced events $M_L \geq 0.0$ (*b*=1.15). Further analysis of the various phases of activity also reveal a strong difference in the seismic response of the two nearby geothermal sites of Landau and Insheim, that might be due to different reservoir characteristics and injection histories.

Earthquake catalog EKDAG V2.0: Macroseismic observations of damaging earthquakes in Southwestern Germany

Beinersdorf, Silke1, Schwarz, Jochen1, and Meidow, Hein2

1 Earthquake Damage Analysis Center □ EDAC □ Bauhaus-Universität Weimar, Germany
2 SeimoGeologisches Büro Dr. Meidow Köln, Germany

Several catalogues are providing macroseismic information and shake maps for Central European earthquakes. In many cases the shaken area is exceeding the national borders indicating the need of data exchange, and update on the basis of a unique scale (like the European Macroseismic Scale EMS-98). The earthquake catalogue EKDAG (Schwarz *et al.*, 2014, 2009) is providing the possibility to join and revise the datasets and supplement them with additional information. The catalogue is available through a GIS-based EDV-system. It is divided into three parts, **Part A** with explanations, **Part B** - the data file and **Part C** as a compilation of reproduced macroseismic maps in GIS format. EKDAG contains the reports and findings with respect to their localization. The maximum shaking effects are re-evaluated on the basis of EMS-98 scale. The maximum observed intensity ($I_{\max,obs}$) is specified. Changes in the catalogue are documented in the database. This allows the interactive use of the catalogue. The conceptual approach beside the maximum shaking effects is to have also the damage repartition and to maintain information about site specific characteristics or "anomalies" concerning macroseismic intensities and effects.
In Part C of the earthquake catalogue EKDAG maximum shaking effects and also the macroseismic findings for the lower intensity ranges are included. They are presented in GIS-format for the main events. These observations and the digital macroseismic database are plotted in Fig. 1. For the Upper Rhine Area some of the major damaging earthquakes are presented according to EKDAG (Fig. 2); entries are compared with those from neighbouring country catalogues of the Upper Rhine Area.

Fig. 1 Macroseismic observations from various sources ● with highlighted observations with an intensity I ≥ VI (6.0) ● of earthquakes acc. to the earthquake catalogue EKDAG V2.0 (Schwarz et al., 2014)

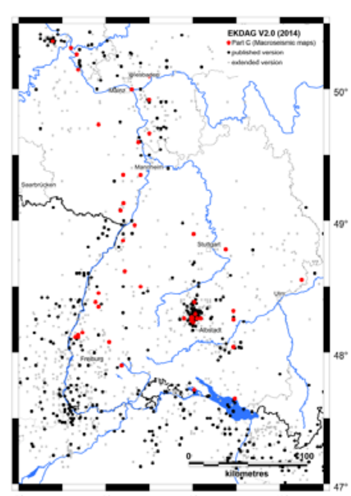

Fig. 2 Earthquake catalogue EKDAG V2.0 (Schwarz et al., 2014) with ● highlighted earthquakes of part C containing macroseismic maps

Earthquake catalogue for southwestern Germany – A status report

Wolfgang Brüstle, Silke Hock, Uwe Braumann, Fee-Alexandra Rodler and Andreas Greve

Regierungspräsidium Freiburg, Abteilung 9 – Landesamt für Geologie, Rohstoffe und Bergbau, Referat 98 – Landeserdbebendienst, Freiburg im Breisgau, Germany
correspondence to wolfgang.bruestle@lgrb.uni-freiburg.de

The Upper Rhine Graben – bordering Germany, France and Switzerland – has a long record of damaging earthquakes throughout the past centuries. Furthermore, since the occurrence of the 1911 earthquake (intensity VIII) the Albstadt region in the centre of Baden-Württemberg has proven itself to be one of the seismically most active regions north of the Alps. Seismic recording has started in southwestern Germany at the beginning of the 20th century, the macroseismic method, however, still prevailed until the beginning of the 1960s. Baden-Württemberg's earthquake service, the "Landeserdbebendienst" (LED) is in charge of data collection and catalogue work. The LED is based at Freiburg im Breisgau, where it is part of the State Geological Survey since 1993. We currently elaborate and complete the earthquake catalogue of Baden-Württemberg for the last millennium in a five-year project. A data base hosts all our catalogue data, including macroseismic data and information about corresponding documents. Existing regional catalogue subsets have been reviewed and included into the data base. Relevant parts of national catalogues have been implemented as well. We have started to acquire digital intensity data points from the original macroseismic questionnaires, from earlier publications and, last but not least, from historical documents. For the first time, a systematic search for information about historical earthquakes in Baden-Württemberg is carried out tracing back historical information to the primary sources. 250 macroseismic maps from archives and various other sources have recently been published in the monograph "Makroseismischer Atlas Baden-Württemberg – 19. und 20. Jahrhundert" (in German, including relevant information in English). About half of these maps show epicentres in the Albstadt source region confirming its seismic activity. The talk will give a status report of the project

Large earthquakes in stable continental plate interiors: The need for a new paradigm

Eric Calais, ENS Paris France, Thierry Camelbeeck, ROB Brussels Belgium
Seth Stein, NWU Evanston USA

The occurrence of large earthquakes in stable continental plate interiors has so far resisted our understanding. Contrary to plate boundary settings, where a balance is achieved over <1000 years between the rates at which strain accumulates and is released in large events, intraplate earthquakes occur in regions where no discernable strain is building up today. In the absence of current strain accumulation, their triggering mechanism remains elusive, as well as the mechanism by which faults having already ruptured in large events might be reloaded to permit sequences of large events, such as in the New Madrid, Central-Eastern U.S., sequence. Earthquake activity in such settings does not seem to be persistent at the location of past large historical earthquakes, which appear to be episodic, clustered and spatially migrating through time. The relationship between long-term geological structures and earthquakes is poorly understood and the ability of intraplate current producing M3-4 events to rupture in M6 and larger earthquakes is unknown. Finally, the fact that the steady-state plate boundary model -- which forms the basis for seismic hazard estimation does not seem to hold in continental interiors makes accurate seismic hazard estimation in such setting particularly challenging. We will review these issues and argue that our understanding of earthquakes in continental plate interiors requires a paradigm shift.

Faults and earthquake activity in northwestern Europe

Thierry Camelbeeck, Kris Vanneste, Koen Verbeeck, Koen Van Noten and Thomas Lecocq
Royal Observatory of Belgium
Avenue circulaire, 3 – B-1180 Brussels

The relationship between geologic faults and seismic activity within stable continental regions is not as evident as at plate boundaries where the accumulated strain during the seismic cycle is mostly released along identified active faults. In the stable plate interior of Europe the Lower Rhine Embayment (LRE) is the only region where slow active faults have been unambiguously identified and related to earthquake activity. Geologically active faults have not yet been identified in the region around the LRE, despite the fact that the three strongest known earthquakes, with estimated magnitude around 6.0, occurred there.

To better characterize the relationship between earthquake activity and faults in this region, it is necessary to improve our identification and knowledge of both the geological structures and the seismic activity. In this presentation, we discuss: (1) the importance to evaluate the long-term persistence of the tectonic activity at the fault zones which are supposed to have generated large and moderate historical earthquakes, and (2) the mechanical conditions supporting the fact that old geological faults can be the source of large earthquakes.

By studying in the geomorphology and the geological records the recent tectonic activity of the Sangatte and Hockay fault zones which generated the large (M~6.0) 1580 - Strait of Dover and 1692 - northern Belgian Ardenne earthquakes, we evidenced that the Quaternary activity of these faults is very elusive if it exists and that such large earthquakes are very infrequent on these faults. These results support the episodic, clustered and migrating character of the seismicity in this stable continental region which is already suggested by the observation that during the last 700 years moderate and large earthquakes always occurred at different locations.

By investigating the relationship between the current seismicity and Caledonian and Variscan structures crossing the Belgian territory, we discuss the ability of these old fault zones to generate large earthquakes. In our conclusions, we emphasize the importance of considering the fundamental mechanical and structural homogeneity differences between active faults in a presently deformed crust, as in plate boundary or active intraplate regions, versus possibly reactivated parts of old structures that survived several tectonic and erosional cycles in a crust where the tectonic stress is mainly related to the differences in gravitational potential energy.

Fault PSHA For the Fessenheim NPP, Eastern France

Christophe CLEMENT, Thomas CHARTIER, Oona SCOTTI,
Stéphane BAIZE, Hervé JOMARD

Institut de Radioprotection et de Sureté Nucléaire

The southern part of the Upper Rhine Graben (URG), a populated and industrial area between France and Germany, presents a relatively important seismic activity for an intraplate area. A magnitude 5 or greater shakes the URG every 25 years and, in 1356, a large magnitude event (M>6.5) struck the city of Basel. Several potentially active faults have been identified in the area, and their relevant seismotectonic parameters are documented in literature. Most of these faults run along the graben borders, but some of them are located within and beneath. According to their size, they are able to produce M≥6 earthquakes. Regional models and preliminary geomorphological investigations provided provisional assessment of slip rates for the individual faults (up to 0.1 mm/a) which give a return periods of at least 10 000 years for M≥6 earthquakes. These events, even if infrequent, are therefore to be considered in nuclear safety which is interested in low probability phenomena (typically 10^{-4}).

We performed a probabilistic analysis using a fault model for assessing the seismic hazard at the Fessenheim Nuclear Power Plant. In this study, we explore the impact of the slip-rate uncertainty on seismic hazard assessment, as well as the impact of different input key parameters such as the fault geometry, the seismicity model associated to the faults (Characteristic / Gutenberg-Richter). Besides the selection of the ground motion prediction equations (GMPEs), the uncertainty on the slip rate is the main cause of variability as the hazard at 10 000 years and more is mostly controlled by the active faults. Introducing faults in the model focuses the hazard at 10 000 years (and more) around the selected faults and changes the shape of the Uniform Hazard Spectrum which defines the level of threat used to design the site. In some cases, it can even reduce the hazard at the site.

These elements emphasize the need for detailed and robust geological datasets. Considering the available data for the southern URG, the implication is that there is a critical need for new and extensive investigations.

A magnitude 6.6 event in the Basel region: From historical and archeological observations to risk scenarios

Donat Fäh, Clotaire Michel, Pia Hannewald, Pierino Lestuzzi, Stephan Husen.

Swiss Seismological Service, ETH Zurich
Sonneggstrasse 5, 8092 Zürich
donat.faeh@sed.ethz.ch

The 1356 Mw 6.6 Basel earthquake is the most significant historical earthquake in the southern Rhinegraben area. Historical and archeological investigations combined with methods from structural engineering have been used to analyze the damage of this event. Paleo-seismological investigations define the return period of such large earthquakes, and a microzonation study highlighted the variability of ground motion in the area. In recent years, the strong motion network has been modernized and the density of stations has been increased to 21 permanent stations. Presently a temporary network is operational as well. In the long-term, the network will allow mapping the active faults. The stations are used to derive empirical frequency-dependent site-amplification from the recorded earthquake ground motion. These amplification functions allow for a verification and improvement of the basic information for site-specific seismic hazard and risk scenarios.

For a reliably simulation of future damage in the city of Basel, it is necessary to combine empirical scenarios (based on macroseismic intensity) with ground-motion based scenarios. For that purpose, a source model, a ground-motion prediction model adapted to the area, a site-amplification map with adequate spatial resolution and a vulnerability model are needed, as well as their associated multivariate probability distributions in order to propagate the uncertainties.

In the frame of the project *Basel Erdbebenvorsorge*, we developed earthquake scenarios for the school buildings in the city of Basel. We use the software Openquake developed in the framework of the Global Earthquake Model (GEM). Scenarios similar to the 1356 Mw 6.6 Basel event, other historical events and events defined through de-aggregation of the probabilistic seismic hazard are simulated. The ground motion at the reference rock is computed using the Swiss stochastic model. The local geology is taken into account through an interpolation of the observed empirical amplification and the numerous geophysical measurements performed in the city in the last 15 years. Moreover, mechanic-based fragility curves are developed for 121 school buildings of the city of Basel, grouped into building types. Propagation of the uncertainties and their correlation is considered in detail.

Recent and future evolution of the seismic network in Alsace and in Northeastern France

Doubre, C., Bes de BercM., Wodling H., Jund H., Grunberg M., Vergne J., Blumetritt H.

EOST - UMS830 - Université de Strasbourg, 5 rue René Descartes

The Ecole et Observatoire des Sciences de la Terre is in charge of one of the regional networks for the national seismic survey in France, managed by the RéNaSS-BCSF. This network was traditionally constituted of 8 short-period stations one-component telemetered from the Vosges, the northern Jura and the central plain of Alsace, all which are collected, analyzed and archived at the central site of Strasbourg. Complementing these stations, the signals of ~5 stations in Germany were likewise sent to Strasbourg in order to constrain the localisation of the earthquakes occurring in this border region. In the frame of several ongoing projects, the monitoring system is evolving substantially in terms of both the equipment and the densification of the seismic network.

First, the RESIF project (REseau SIsmologique et géodésique Français) has the objective to make the French national seismic network more dense, more homogeneous and more modern over the whole continental territory. This implies that the regional network, including the Champagne and the Burgundy regions, will eventually consist, in 2018, of ~20 broad-band stations transmitted in real-time with DSL or 3G to Strasbourg in order to be integrated into the earthquake location routine process. These stations will be of high quality regarding the noise level, by installing them under strict criteria of instrumentation into underground mine and tunnel sites, boreholes or down-holes.

Second, a project managed by Electricité de Strasbourg and EOST and funded by ADEME has the objective of densifying the seismic network in and around the plain of Alsace with 8 new stations in order to decrease the magnitude threshold below 1.5. The aim of this project is to allow the EOST to get an independent and well-constrained ability to monitor the tectonic seismicity and human-induced seismic activity, in particular that related to geothermal exploitations which are being developed in this region in the near future.

Third, thanks to the Labex G-eau-thermie profonde, the regional seismic network encompasses a 200 m-deep broad-band borehole sensor, associated with a strong motion sensor, in the area of Soultz-sous-Forêts.

This new seismic survey network will be complemented by a total of ~20 both short-period and broadband stations in Germany, Switzerland, Luxembourg and Belgium. In addition, a series of ~11 strong motion stations, managed by the Réseau Accélérométrique Permanent (RAP) is distributed over the Alsace, Vosges and Jura area.

Combined leveling, triangulation and survey-mode GPS data in the southern Upper Rhine Graben: A review of centennial-old data to estimate crustal deformation.

Ferhat G., M. Meghraoui, and F. Masson

Institut de Physique du Globe de Strasbourg - UMR7516 CNRS/Université de Strasbourg
gilbert.ferhat@unistra.fr

The Upper Rhine Graben (URG) is a north-northeast trending intraplate structure, which belongs to the European Cenozoic Rift System. This area is of low-level instrumental seismicity, even if some M_L 5 earthquakes occurred recently. This region experienced a major historical earthquake in 1356 in Basel (Io IX-X MKS). We seek to quantify the present-day deformation in the URG using different datasets from various methods of geodetic measurements. A review of leveling comparisons shows vertical movements due to tectonic subsiding/uplifting processes but also due to other effects such as water-table fluctuations and surface subsidence due to pumping. To estimate the horizontal deformation across the URG, diverse geodetic data, i.e. old triangulation and trilateration data, combined with recent GPS campaigns performed in the Vosges, Jura and Black Forest mountains have been analyzed. Aufranc (2000) combined 1876-1985 triangulation/trilateration date and 2000 GPS data to estimate small deformation in the Southern part of the URG and Northern part of the Jura. The combination of GPS data performed in 1993, 1998, 1999, 2004 and 2009 revealed eastward horizontal velocities ranging from 0.8 to 1.4 mm/yr, very close to their respective uncertainties. Since the expected horizontal deformation is very low in this area, we propose to re-measure in 2015 (and in the next years) some of the sites observed in 2000 by Aufranc (2000), and add some GPS-Alpes sites observed since 1993 in the Vosges and Jura mountains.

Aufranc, A., 2000, Mesures de la deformation crustale dans le fossé rhénan par comparaison des mesures GPS/Triangulation, Mémoire de l'Ecole Nationale Supérieur des Arts et Industries de Strasbourg, 60 pp.

The Armedea project: Archaeology of medieval earthquakes in Europe (1000-1550 AD)

Forlin, P. (1), Gerrard, C. (1), Petley, D. (2)

(1) Department of Archaeology, Durham University, South Road, Durham, DH1 3LE, UK.
E-mail: paolo.forlin@durham.ac.uk
(2) School of Environmental Science, University of East Anglia, Norwich Research Park, Norwich, NR4 7TJ, UK

A new Marie Curie funded project named Armedea (*Archaeology of medieval earthquakes in Europe, AD 1000-1550)* is collecting and analysing the archaeological evidence related to medieval seismic events in Europe.

The main objectives of the Aremdea project are fourfold:

1- To develop a geographical database (GIS) of seismic events in the Middle Ages drawing on existing catalogues and untapped 'grey literature';

2- To create a 'risk map' for medieval Europe which indicates the potential threat of major seismic hazards to different regions and centres of population;

3- To investigate a sample of well-documented episodes using a combination of remote sensing and fieldwork through the selection of specie case-studies.

4- To understand the 'risk-sensitive tactics' adopted by medieval societies in different regions, particularly their resilience and hazard reduction strategies.

This research is shedding new light on strategies adopted by the medieval communities in terms of resilience and hazard mitigation of seismic risk. Thanks to a comparative approach, based on GIS analysis, we are analysing together seismic effects and reaction to seismic damage in archaeological contexts.

The proposed presentation will introduce the guidelines of the Armedea project and its first fieldwork activities in Cyrpus, Italy, Azores and Spain (www.armedea.wordpress.com).

3D Surface Displacement Rates in the Upper Rhine Graben Area from a Combination of Levelling, GNSS and InSAR

T. Fuhrmann, M. Mayer, M. Westerhaus, K. Zippelt, B. Heck

Geodetic Dept., Karlsruhe Institute of Technology

In recent times, the URG area is characterised by moderate seismicity and small tectonic movements (less than 1 mm/a). However, the recent surface displacements are not well constrained from previous geodetic studies, mainly because the database used was not sufficient to estimate reliable displacement rates at the sub-mm/a scale for the whole URG area. Having access to a large amount of geodetic data from levelling, GNSS and InSAR, we derived a consistent 3D velocity field for the URG from a two-step approach. First, we carry out single-technique analyses in order to estimate linear displacement rates. In the second step, we consistently combine the geodetic datasets exploiting the advantages of each technique.

We use data sets from levelling campaigns, permanent GNSS sites and ESA's satellite missions ERS-1/2 and Envisat (both on ascending and descending tracks). Precise levellings carried out by the surveying authorities of Germany, France and Switzerland form a network of levelling lines. The levelling benchmarks have been measured up to 5 times since the end of the 19th century. A kinematic network adjustment is applied on the levelling data, providing an accurate solution for vertical displacement rates at levelling benchmarks. In addition, coordinate time series starting in 2002 at more than 80 permanently operating GNSS sites of the GNSS Upper Rhine Graben Network are analysed point-wise primarily to support the derivation of the horizontal velocity field of the URG region. Finally, InSAR is used to fill gaps and to significantly increase the spatial coverage of the measurements. ERS-1/2 and Envisat scenes covering a period from 1992 to 2000 and 2002 to 2010, respectively, are processed using StaMPS (Stanford Method for Persistent Scatterers) in order to obtain line of sight displacement rates at PS points in the URG area.

The data sets from InSAR, levelling and GNSS are inhomogeneous in space and time. When combining the displacement results, we implicitly assume that (i) the three techniques measure the same signal, (ii) the tectonic displacements behave linearly in time and (iii) the tectonic signal is smooth in space and does not abruptly change within short distances. The latter requirement is of special importance as we use Kriging to interpolate the different data sets to a common location. Most of the non-linear movements in the area of investigation could be assigned to anthropogenic deformations which have been investigated in several case studies.

All three techniques are datum-dependent and measure displacements relative to a reference point (levelling), a reference area (InSAR) or a reference frame (GNSS), which are located in different regions. To remove these significant differences, we firstly calculate offsets between InSAR and levelling for the vertical component and between InSAR and GNSS for the horizontal component in order to shift the rates obtained from InSAR into the datum of levelling and GNSS. For the combination, we interpolate the displacement rates of all the three techniques to a common grid. In order to avoid spatial extrapolation, this grid only carries values in the vicinity of PS points. At every valid grid point, the linear LOS velocity rates from PS-InSAR (ascending and descending) are combined with vertical velocity rates from levelling and horizontal velocity rates from GNSS resulting in a 3D velocity vector (Northing, Easting, Up).

The small horizontal and vertical linear rates recovered from our geodetic analysis are in accordance with geological and geophysical models and indicate that our combination approach is able to resolve tectonic movements at the sub-mm/a level with a formal error of 0.1 mm/a and 0.3 mm/a for the vertical and horizontal components, respectively. Our results recover the recent intraplate deformation of the URG area with unprecedented accuracy and spatial resolution.

New paleoseismological data from the Rurrand Fault, Lower Rhine Basin

Christoph Grützner* (1), Jochen Hürtgen (2), Peter Fischer (3), Klaus Reicherter (2)

(1) Bullard Laboratories, Department of Earth Sciences, University of Cambridge, Madingley Rise, Madingley Road, CB3 0EZ Cambridge, UK. chg39@cam.ac.uk
(2) Institute of Neotectonics and Natural Hazards, RWTH Aachen University, Lochnerstr. 4-20, 52064 Aachen, Germany
(3) Institute for Geography, Johannes Gutenberg-Universität Mainz, Johann-Joachim-Becher-Weg 21, 55099 Mainz, Germany

Faults in the Lower Rhine basin in Western Germany have slip rates of less than 0.1 mm/yr, which does not allow ongoing tectonic deformation to be investigated with the currently available geodetic techniques like levelling, GPS, and InSAR. Due to the very long recurrence intervals of large earthquakes of several thousands of years, instrumental seismicity bears only limited information on the large events. The instrumental record includes no earthquake with Mw>5.5, but from paleoseismology it is known that much stronger events did occur in the past. Therefore, paleoseismological studies are needed to constrain slip rates and earthquake history of such slow active faults. Here we document new paleoseismological data from the Rurrand Fault. This normal fault strikes NW-SE, dips to the SW and is a possible candidate for the 1755/56 Düren earthquake series. It consists of three slightly overlapping segments of 12 km, 16 km, and 18 km and its total length is 40 km. This fault has been subject to paleoseismological studies in the past with contradicting results. Late Quaternary paleoevents have been proven, but there is an ongoing debate about the date of these events, their number, and their magnitude. In a new outcrop that became accessible during construction works we found clear evidence for surface rupture in the Holocene. We identified additional three surface rupturing events that happened in the Late Pleistocene. Coseismic offsets were between 0.1 – 0.5 m per event, which corresponds to magnitudes of M_W5.9-6.8 and a slip rate of not less than 0.02-0.03 mm/yr. Recurrence intervals for such events are as long as few tens of thousands of years. The surface ruptures that we identified did not occur at the main fault trace, but on a younger fault strand in the hanging wall of the main fault. We used 1 m resolution airborne LiDAR data in order to image the morphological expression of this young fault zone. A linear feature of few hundreds of meters length could be identified. We cannot say whether this lineament is due to the last earthquake activity of the fault zone or if it is rather due to differential vertical movements caused by the lowering of the groundwater table for a nearby open pit lignite mine. In both cases, however, it marks the fault trace and can be used to map this fault strand. We used shallow geophysical to image the fault zone at depth. Georadar did not produce unambiguous results, but electric resistivity tomography was successfully applied and allowed us to estimate slip rates. Our findings imply that the Rurrand Fault did not produce surface ruptures during the Düren 1755/56 earthquakes. Two explanations are possible: 1) If these quakes occurred at the Rurrand Fault, they were probably not surface rupturing events (not strong enough, shallow slip deficit, too deep, or a highly heterogeneous surface rupture pattern); 2) The Düren earthquakes did not occur at the Rurrand Fault.

Current surface displacements observed from TerraSAR-X InSAR monitoring at local scale in the Upper Rhine Graben

Christine Heimlich, Frédéric Masson, Cécile Doubre

Institut de Physique du Globe, Strasbourg

This study presents the results of InSAR monitoring at regional scale in the Upper Rhine Graben. The studied area is located on the western part of the Upper Rhine Graben, from the Soultz-sous-Forêts area (North Alsace, France) to Laudau (South Rheinland Pfalz, Germany). We processed SAR images acquired by TerraSAR-X satellite between May 2012 and January 2015 with StaMPS software using Persistent Scatterers method (Hooper et al., 2004). We then access to the surface deformation of the ground in the studied area and its time evolution, which allows to characterise the deformation as steady-state or transient. Despite the short time duration of our time series, several areas affected by surface displacements are identified. Most of them are clearly associated with industrial activity.
First, in the German area (Landau), we observe four kinds of displacements.
At larger scale, we observe 1) a subsidence that is consistent with path levelling measurements, 2) an uplift in the North of Landau located on a horst, 3) a pluricentimetric vertical displacements centred on a geothermal power plant location and 4) an non-homogenous uplift over the city of Landau along a North-South orientation.
The signal around the geothermal power plant location exhibits a ~2 km-diameter circular pattern, suggesting that this deformation has an anthropogenic origin. And the time series analysis of this displacement suggests that it is related to a technical incident that occurred in June/July 2013. The North-South uplift is temporally associated with this signal but remains unclear : it could be related to either the geothermal power plant incident, the oil field exploitation, the water pumping, the displacements on the main tectonic faults or a combination of these processes ? The analysis of the displacements has to be completed with other geodetic and geophysical data and modelling in order to better estimate the influence of each cause.
Second, our map of the ground velocty reveals low deformation in Surbourg, Pechelbronn, Wissembourg. In these areas, several faults have been identified in seismic profiles acquired in the region, but their current activity is still debated. With our data, we quantify their movements to ~1 to 4 mm/yr.

Archaeoseismology, can it extend our archives?

Klaus-G. Hinzen
Earthquake Geology and Archaeoseismology
Cologne University

While Historical Seismology has played a crucial part in the compilation of earthquake catalogs since the earliest days of observational seismology and Paleoseismology has evolved as a well-established branch of the science since several decades, the application of archaeological seismology to deduce ground motion parameters or even earthquake parameters is the most recent of these non-instrumental techniques. Particularly in regions with relatively low instrumental seismicity, *e.g.* the Jordan Valley, the Argolis, the Esçen Basin, the Vienna Basin, and the Upper and Lower Rhine Graben, any earthquake record from pre instrumental eras is of high importance. The majority of published archaeoseismic studies originate from the Mediterranean; however, several locations north of the Alps including *Carnuntum*, *Augusta Raurica*, Kerkrade, Kückhoven, *Tolbiacum,* and Cologne have been targeted. In this contribution, we outline the procedures of quantitative archaeoseismic studies in general and summarize results achieved in Lower Rhine Graben.

A Neolithic wooden well was discovered and excavated between 1989 and 1992 near Erkelenz in the Lower Rhine Embayment. The construction, 3 x 3 m in size and 13 m deep, was exceptionally large for its time, dated to 5090 BC by dendrochronological analysis. At 8 m depth several elements of the large oak box were vertically sheared off and the broken parts moved inward and downward. As the well is located only 3 km from one of the active tectonic faults in the Lower Rhine Embayment, a seismogenic origin of the damage was considered and tested. However, ground deformation and relative displacement calculated with a finite element model of the casing were found to be too small to account for the documented damage.

Archaeological excavations carried out from 2001 to 2003 at the vicus *Tolbiacum* site, unearthed heavily damaged and ruined late Roman fortification works. Damage includes 0.17 m wide tensile cracks in a 3.1 m wide wall, tilted walls and fortification towers, horizontal displacement of wall sections of 0.95 m, and rotation of wall fragments. Engineering seismological models and site-specific strong motion seismograms calculated with calibrated Q- and duration models and nonlinear site amplifications were used to test the hypothesis. Since man-made activities, running water, and slow-acting gravitational causes could be excluded, the damage is regarded as most probably seismogenic, and site intensity is assessed at IX. This result marks the first intensity above VIII for a tectonic earthquake in Germany. Dating results (14C) indicate the second half of the fourth century A.D.

Ongoing excavations in the city center of Cologne have revealed numerous deformations of remains from the Roman period to WWII. The uncovered ground extends 175×180 m. A comprehensive model of the excavation area based on more than 200 laser scans allowed a systematic analysis of the damage patterns and a geotechnical model of the site as it was during Roman/Medieval times. Five locations with different damage patterns were analyzed in detail. Site-specific synthetic strong ground motion seismograms were used to test the possibility of earthquake-induced ground failure as a cause for the observed damage. And alternatively, the possibility of hydraulically-induced damage by seepage and erosion of fine-grained material from stray sand was studied. Heavy rainstorms can induce a direct stream of surface water through the fine sand layers to the ground water table. Simulated ground motion for assumed worst-case earthquake scenarios did not provoke slope instability at the level necessary to explain the structural damages.

Detailed seismological studies using observations of dense seismic network: the case of the Dead Sea basin

Hofstetter R.[1,2], Dorbath C.[2,3], and Dorbath L.[2]
1. Geophysical Inst. of Israel, Lod, Israel
2. Ecole et Observatoire des Sciences de la Terre, Strasbourg, France
3. IRD, UMR 154. Toulouse, France

Improving the seismic hazard assessment in a given region is a prime target as it may a direct implication on large population. It also involves determination of the local and regional effects induced by large-scale plate tectonics and the subsequent deformation field, which can be achieved through the knowledge of the regional stress field. In this study we take advantage of the large database of seismological observations in the Dead Sea basin, including the recently acquired observations by the permanent and temporary networks, to get a better definition of the stress field. We conducted several successful studies of the Dead Sea basin and its vicinity, using local, regional and teleseismic observations, which yielded important results. The large number of arrival times and polarities from nearby and regional stations allowed obtaining high precision relocations of earthquakes with good and reliable azimuthal coverage and also computations of focal mechanisms. There is a good agreement between the locations of the earthquakes and the active faults, based on geological data, and also between the fault plane solutions and the orientation of the active faults. The spatial distribution of epicenters supports a detailed study of the structure of the Dead Sea basin. We determined the stress tensor for several sub-regions, based on tectonic regionalization, to evaluate the impact of each cluster of earthquakes on the solution.

Systematic compilation of paleoseismic evidence in Germany and adjacent areas

Jochen Hürtgen (1), Thomas Spies (2), Jörg Schlittenhardt (2), Klaus Reicherter (1)

(1) Neotectonics and Natural Hazards Group, RWTH Aachen, Lochnerstr. 4-20, 52056 Aachen, Germany. Email: j.huertgen@nug.rwth-aachen.de

(2) BGR, Unit 'Seismic Hazard Assessment', Stilleweg 2, 30655 Hannover.

Central Europe is an intraplate domain which is characterized by low to moderate seismicity with records of larger seismic events occurring in historical and recent times. These records of seismicity are restricted to just over one thousand years. This does not reflect the long seismic cycles in Central Europe which are expected to be in the order of tens of thousands of years. Therefore, we have developed a paleoseismic database (PalSeisDB v1.0) that documents the records of paleoseismic evidence (trenches, soft-sediment deformation, mass movements, etc.) and extends the earthquake record to at least one seismic cycle. It is intended to serve as one important basis for future seismic hazard assessments. PalSeisDB v1.0 will serve to fulfill the requirements of the updated German Nuclear Safety Standard, called KTA 2201.1 (Design of Nuclear Power Plants against Seismic Events). The revised version of this standard explicitly demands the use of paleoseismic studies which results should be considered in the estimation of the maximum historical or prehistorical reference earthquake. The new standard should include the assessment of paleoseismicity up to a distance of 200 km (radius) around the specific site. The collected information in PalSeisDB v1.0 is useful in the context of nuclear safety, but also for building regulations in a more general context (e.g. emergency facilities or infrastructure).

Evidence for paleoearthquakes can be found in different tectonic settings and can have different appearances related to the source of the earthquake. We distinguish between effects found in the vicinity of a fault (on-fault) and effects found at a distance from a fault (off-fault). PalSeisDB v1.0 includes paleoseismic studies from trenching sites which provide the most reliable evidence for paleoearthquakes (e.g. surface faulting). At a distance from the fault, secondary effects can be observed, such as earthquake-induced soft-sediment deformation (e.g. liquefaction) and mass movement features. The extent and distribution of these effects are also strongly dependent on the earthquake's size and magnitude, hypocentral depth, surface and subsurface characteristics. These types of evidence, and others, can be used to identify paleoearthquakes and tectonically active structures and to determine their seismic hazard potential.

In the compilation of PalSeisDB, paleoseismic evidence features are documented at 95 different locations in the area of Germany and adjacent regions. In total, 86 paleoearthquakes have been determined, mostly from paleoseismic trench studies, but also from other paleoseismic studies regarding soft-sediment deformation and mass movements, as well as other paleoseismic evidence (e.g. tsunamigenic deposits, broken speleothems, etc.). Evidence for most of the paleoearthquakes (70 events) have been dated within a time period between 25,000 years BP and historical times. The nine oldest earthquakes even date back to a time period between Eemian and Mid-Pleistocene times. 75 earthquakes have values of magnitudes higher than Mw 5.7 and 53 earthquakes higher than Mw 6.5.

The Earthquake Catalogue of Germany, current status and future plans

Diethelm Kaiser, Dietmar Bürk, Gernot Hartmann

Federal Institute for Geosciences and Natural Resources, Hannover, Germany

The earthquake catalogue of Germany is maintained by the Federal Institute for Geosciences and Natural Resources (BGR). Up to now, two data archives were used to keep and maintain the information: the (historical) earthquake catalogue for Germany for the years 800 – 2008 with about 12 000 events of magnitude ML ≥ 2.0 **[1]** and the "Data Catalogue of Earthquakes in Germany and Adjacent Areas" with currently approximately 21 000 instrumentally analysed earthquakes since 1975 **[2]**. Currently, these two catalogues are integrated into a common database. We developed concepts to realize the requirements in terms of data model and functionality **[3]**.

The adjusted data model of the database used for the instrumentally recorded earthquakes allows to store the macroseismic information, to build and extend the scheme of relationships among the references (publications and historical documentary sources) for an event, to keep track of modifications to events (change history), to prioritize the epicentre, the magnitude and the epicentral intensity, and to label erroneously inserted events as 'rejected/fake'.

A web application has been developed to query events based on individual attributes (e.g. temporal or spatial criteria), to export the selection or the catalogue as a whole, to plot the results of the query on a map, to edit single events, and to import and merge catalogues from other institutions.

The combination of the two catalogues requires the identification of identical parameter sets for same events, and, in case of inconsistent parameters, the prioritization of the available solutions, or the correction of the detected errors.

In the future we plan to import and merge catalogues from other institutions, to build up an archive of macroseismic data points, to estimate homogeneous magnitude values for all earthquakes and to investigate prominent historical earthquakes from their original sources.

[1] LEYDECKER, G. (2011): Earthquake catalogue for Germany and adjacent areas for the years 800 to 2008. – Geolgisches Jahrbuch, E59. (*http://www.bgr.de/quakecat_en*)

[2] Data Catalogue of Earthquakes in Germany and Adjacent Areas. – Federal Institute for Geosciences and Natural Resources. *http://www.bgr.bund.de/erdbebenkatalog-deutschland*

[3] KAISER, D., BÜRK, D., HARTMANN, G., STELLING, U. & SCHLOTE, H. (2014): Integration of catalogues of historical and instrumentally recorded earthquakes in Germany in a common database – concepts, uses, and products. Second European Conference on Earthquake Engineering and Seismology (2ECEES), Istanbul. *http://www.eaee.org/Media/Default/2ECCES/2ecces_esc/3202.pdf*

The Byzantine walled obelisk of Istanbul and an unknown earthquake from the 10-11th century

Miklós Kázmér

Department of Palaeontology, Eötvös University, Budapest, Hungary
E-mail: mkazmer@gmail.com

There is a strange construction in the former Hippodrome of Constantinople (now Istanbul, Turkey) south from the famous Egyptian granite monolith obelisk. It is highly similar to the granite one, but displays considerable differences at close view. First: it is white, made of marble. Second, it was constructed from ashlars, walled up to 32 m elevation, instead of carved from a single piece of rock. This is why is is called the walled obelisk. Third, it bears numerous evidence that external stress affected the column during the centuries.

We don't know when and who built it. An inscription on the southeastern face informs us that Emperor Constantine Porphyrogennetus restored the aging column, decorating it with gilded bronze plates. He ruled from AD 913 until 959. Today all of the bronze plates are missing. It is suspected that these were looted by the Venetians during the sack of Constantinople in 1204, upon the order of Enrico Dandolo, then Doge of Venice. Bronze objects of art were highly prized at that time. The four bronze horses now seen on top of the San Marco cathedral arrived in Venice at the same time, by the same way, from the same Hippodrome. At that time the craft of bronze casting was unparalleled in Constantinople. Bronze plates, ordered from workshops there during the 11th century, still adore the doors of various Italian cathedrals today.

There is no information about the obelisk's fate until the late 19th century, when much of it was disassembled and re-built for restoration.

The base of the obelisk is a marble cube, 3.2 x 3.2 x 2.2 m. There are open fractures (now covered and filled by poor repair), penetrating the body both at corners and in the middle of certain faces.

There is a multitude of small, rectangular holes, up to 5-10 cm deep, 3-5 cm wide, arranged without any particular order, on each face of the basement block, except on the one with the inscription. There are similar holes in the ashlars of the column proper. These holes most probably are mortises, served to hold the steel or bronze tenons which fixed the bronze plates to the basement and column. Today there are no tenons and no embedding lead either; these valuable materials were mostly recycled during later, metal-starved periods.

At close sight, fractures radiate from some of the mortises. There are fractures in any direction, usually not longer than a few decimetres, sometimes connecting neighbouring holes. Some fractures never reach the edges of the basement marble block.

We suggest that these fractures were produced while the bronze plates were still attached to the obelisk. A sudden seismic impact tilted the column and the basement, exerted stress on the tightly arranged, rectangular bronze plates, slightly moving them. This stress was transferred to the steel clamps, and consequently, fractured the marble.

It is suggested that a yet unknown major earthquake hit Constantinople during the 9-10th centuries. Evidence for seismic damage is preserved in the fractured marble blocks of the walled obelisk in the Hippodrom. This earthquake is not mentioned by Ambraseys in his Earthquakes in the Mediterranean and Middle East (2009).

Reassessment of the rifting process in the Western Corinth rift from relocated seismicity

S. Lambotte[1,2], H. Lyon-Caen[1], P. Bernard[3], A. Deschamps[4], G. Patau[3], A. Nercessian[3], F. Pacchiani[1,6], S. Bourouis[5], M. Drilleau[1,7], P. Adamova[1,8]

[1] *Laboratoire de Geologie, Ecole Normale Supérieure, CNRS, Paris, France.*
[2] *Institut de Physique du Globe de Strasbourg, CNRS UMR7516, Strasbourg, France.*
E-mail: sophie.lambotte@unistra.fr
[3] *Departement de sismologie, Institut de Physique du Globe de Paris, CNRS, Paris, France.*
[4] *Geoazur, CNRS, Nice, France.*
[5] *Centre de Recherche en Astronomie, Astrophysique et Géophysique, Route de l'observatoire, 16006 Bouzareah, Algeria.*
[6] *now at WAPMERR, Geneva, Switzerland.*
[7] *now at Laboratoire de Planétologie et Géodynamique, CNRS, Nantes.*
[8] *now at Academy of Sciences, Institut of Geophysics, Prague, Czeh Republic.*

The seismic activity in the western part of the Corinth rift (Greece) over the period 2000-2007, monitored by a dense network of three-component stations, is analyzed in terms of multiplets and high precision relocation using double difference techniques. This detailed analysis provides new insights into the geometry of faults at depth, the nature and the structure of the active zone at 6-8 km depth previously interpreted as a possible detachment, and more generally into the rifting process. The seismicity exhibits a complex structure, strongly varying along the rift axis. The detailed picture of the seismic zone below the rift indicates that its shallower part (at depths of 6-8 km) is 1-1.5 km thick with a complex micro-structure, and that its deeper part (at depths of 9-12 km) gently dipping to the north (10-20◦) is 0.1-0.3 km thick with a micro-structure consistent with the general slope of the structure. Although the nature of this seismic zone remains an open question, the presence of seismicity beneath the main active area, the strong variability of the structure along the rift over short distances, and the complex microstructure of the shallower part revealed by the multiplet analysis are arguments against the hypothesis of a mature detachment under the rift: this active zone more likely represents a layer of diffuse deformation. The geometry of the mapped active faults is not well defined at depth, as no seismicity is observed between 0 and 4 km, except for the Aigion fault rooting in the seismic layer at 6 km depth with a dip of 60◦. A distinct cloud of seismicity may be associated with the antithetic Kalithea fault, on which the 1909 Fokis earthquake (Ms=6.3) may have occurred. The link between the 1995 rupture (Ms=6.2) and the faults known at the surface has been better constrained, as the relocated seismicity favors a rupture on an offshore, blind fault dipping at 30◦, rather than on the deeper part of the Helike fault. Consequently, the 1995 event is expected to have decreased the Coulomb stress on the Helike fault. To explain these seismic observations along with the geodetic observations, a new mechanical model for the rifting process in this region is proposed, involving non-elastic, mostly aseismic uniform NS opening below the rift axis, coupled with the downward and northward growth of a yet immature detachment: the reported GPS rates would mainly result from this deep, silent source, and the seismicity would reveal the detachment position, not yet connected to the ductile lower crust. In such a model, the strong fluctuations of microseismicity would result from small strain instabilities, undetected by continuous GPS and possibly related to pore pressure transients.

The Alpine Fault: Paleoseismicity of 'le premiere faille' in New Zealand

Langridge, R.M.,

GNS Science, Avalon, Wellington New Zealand.

The Alpine Fault is most active onland fault in New Zealand and has measured slip rates of 8-29 mm/yr along its length. The Alpine Fault is the main plate boundary fault in the central and southern South Island, and is capable of generating Mw 8 earthquakes every 260-330 yr on average. However, due to the short historic period in New Zealand we are yet to experience an Alpine Fault event.

New research includes the structure, slip rate and paleoseismic studies to improve the understanding of the potential of the Alpine Fault. This talk documents several studies that the author and many colleagues have been involved in along the southern, central and northern sections of the fault. In recent years advances have been made by finding off-fault paleoseismic sites (ponds, lakes) with abundant radiocarbon dating potential with which very long records can be developed, and by the acquisition of LiDAR along the centralmost part of the fault. LiDAR coverage has been particularly important in conjunction with the Deep Fault Drilling Project (DFDP), where it has been used to re-interpret the structure of the fault, measure slip and slip rates, and to locate paleoseismic sites.

Paleoseismicity of Normal Faults in Active Intra-arc and Back-arc Settings: Examples from New Zealand, Mexico and Oregon

Langridge, R.M., Villamor, P.

GNS Science, Avalon, Wellington New Zealand

Continental volcanic arc and back-arc regions are also zones of active normal faulting that carry potential for surface rupture and damaging ground motions during moderate to large earthquakes. These regions include the Taupo Volcanic Zone (TVZ; New Zealand), Trans-Mexican Volcanic Belt (TMVB) and northwestern Basin and Range (NWBR; Oregon). Due to the short historical records of large earthquakes in these areas, paleoseismic studies are required to bridge the gulf in time between the instrumental and geological periods.

In the TVZ, the largest known historical earthquake occurred in March 1987. The M 6.3 Edgecumbe earthquake ruptured a suite of faults and caused widespread damage to industrial and suburban assets. The event underlies the potential for complex moderate to large TVZ earthquakes. Mapping of active indicates there are numerous active normal faults along- and across-strike in the TVZ. Trenching of these faults indicates recurrence intervals for these faults of <2000 yr, therefore the role of these faults is relevant to local and national scale seismic hazard. Extensive trenching and GPR studies of faults near the major rhyolitic caldera complexes has allowed for the recognition of discreet faulting events that can occur pre-, during or post- major tephra and ignimbrite eruption events.

Rates of extension are typically lower across the TMVB; c. 0.3 mm/yr vs. 5-7 mm/yr for the TVZ. However, the occurrence of the destructive November 1912 M 6.9 Acambay earthquake highlights the potential of these faults. Trenching of the Acambay graben master faults indicate that they have recurrence intervals of several thousand years. Back-arc faults of the NWBR in SE Oregon have a similar rate and seismic potential to those in the TMVB, but have not yet yielded large earthquakes as yet. Studies of the Ana River and other faults indicate long surface ruptures with long recurrence times, documented from faulted, tephra-rich lacustrine sections. These studies all highlight the need to combine historical seismicity and records with paleoseismic studies of faults that can address the medium to long term activity of normal faults in both plate margin and intra-plate settings.

Fluid-induced earthquakes with variable stress drop

O. Lengliné[1], L. Lamourette[1], L. Vivin[1], N. Cuenot[2] and J. Schmittbuhl[1]

[1]Université de Strasbourg, EOST, IPGS, CNRS, Strasbourg, France
[2]GEIE Exploitation Minière de la Chaleur, Kutzenhausen, France

The static stress drop of an earthquake, which quantifies the ratio of seismic slip to the size of the rupture, is almost constant over several orders of magnitudes. However, although variations are sometimes observed, it is difficult to attribute these variations either to a well-defined phenomenon or simply to measurement uncertainty. In this study we analyze the static stress drop of earthquakes that occurred during a water circulation test in the Soultz-sous-Forêts (France) geothermal reservoir in 2010. During this circulation test, 411 earthquakes were recorded and the largest event reached a magnitude MD2.3. We show that several earthquakes in the reservoir can be combined into groups of closely located similar repeating waveforms. We infer that, the amplitudes, and hence magnitudes, vary between the repeaters although the waveforms and spectra are similar. We measure similar corner frequencies for these events despite their different magnitudes, suggesting a similar rupture size. Our results imply that events at the same location may exhibit stress drop variations as high as a factor of 300. We interpret that this variation in stress drop is caused by fluid pressure at the interface reducing the normal stress on the interface. We also hypothesize that the observed variations reflect a transition from stable to unstable slip on the imaged asperities.

Tectonic heritage control on intraplate strain and seismicity rates

Stephane Mazzotti and Frédéric Gueydan

Geosciences Montpellier

Rates of seismicity and associated deformation in intraplate domains are typically poorly constrained. Limits of earthquake catalogs and paleo-seismology data often restrict the estimated strain rates to orders of magnitude, with little knowledge on their steady-state or transient characters. Similarly, geodetic methods often yield only upper bounds on present-day strain rates. Here we propose to constrain first-order continental strain (and seismicity) rates using lithosphere rheological models driven by tectonic forces and including new strain-weakening rheologies associated with tectonic heritage. In intraplate weak zones such as the Rhine Graben, structural and tectonic heritage results in significant weakening and yields strain rates several orders of magnitude higher than those in background (no-heritage) regions. These results provide first-order constraints on long-term deformation rates and, with strong assumptions, on long-term seismicity rates. We explore upper and lower bounds of possible strain and seismicity rates in several typical intraplate weak zones, including the Rhine Graben.

The 1952 seismic sequence of the northern Upper Rhine Graben: Focal depth and clues for a larger earthquake rupture.

Meghraoui, M., Sira, C. and Rime C. H
Institut de Physique du Globe, UMR 7516, Strasbourg

Historical and instrumental seismicity of intraplate Europe shows the occurrence of moderate to large damaging earthquakes in the Upper Rhine Graben (URG). Beside the large 1356 earthquake of Basel (Io = IX, Mw 6.5) that occurred in the south URG, moderate (with M < 6.5) but damaging earthquakes did occur in 1289, 1574, 1728, 1733, 1737, 1871, 1903 and 1933. We present here the damage distribution of the earthquake sequence of 1952 that affected the western edge of the northern URG. The sequence initiated in 24/02/1952 (Io VII, MKS) in the northern area near Mannheim (Germany), with a second shock on 29/09/1952 (Io VII) and maximum damage between Landau and Wissembourg (France), and a third shock on 08/10/1952 (Io VIII) with maximum damage between Wissembourg and Haguenau (France). Located along the graben western shoulder, this seismic sequence also follows the ~110-km-long Riedseltz-Worms fault zone and shows a southern migration of the macroseismic area. The detailed damage investigations, isoseismal shape and inferred epicentral location lead to shallow hypocentral depth (< 8 km). Exposed outcrops of faulted late Quaternary units (loess, < 30 ka), prominent and linear scarps on alluvial fans and geomorphic markers of drainage control along the fault zone imply the occurrence of late Pleistocene and Holocene faulting. Although made of moderate earthquakes (Mw<6.0), the 1952 seismic sequence and its correlation with the Riedseltz-Worms fault zone shows the potential for Mw 6.5-7 earthquake in the northern URG. The historical and instrumental earthquake distribution in the northern URG indicates a clear lack of moderate to large seismic events and therefore a seismic gap that may depend on the episodic behaviour of active faults in intraplate tectonic domain. Paleoseismic results show that return periods for earthquakes similar to the 1356 Basel event are of the order of 2500 years. Considering that reliable historical seismic records may not date back to more than 1000 years, it implies that other large undocumented earthquakes in the region may be missing in the seismicity catalogue.

Interpreting Seismotectonics for Seismic Hazard in Intraplate Areas: The British Isles as a Case Study

Musson, R. M. W.

British Geological Survey
West Mains Road, Edinburgh EH9 3LA UK
rmwm@bgs.ac.uk

In intraplate areas there is often no obvious correlation between seismicity and geological structure, which makes it difficult to construct seismic source models for probabilistic seismic hazard assessment on the basis of geological information. As a result, many practitioners have given up the task in favour of purely seismicity-based models. This risks losing potentially valuable information in regions where the earthquake catalogue is short compared to the seismic cycle. The British Isles are a good example of an area where the distribution of earthquakes is clearly neither uniform nor random, yet spatial patterns do not obviously follow geological features.

The earliest studies of British seismic hazard did not consider regional tectonics in any way, but over time there has been a gradual evolution towards more tectonically-based models. A number of speculative hypotheses have been put forward. Some of these propose association of seismicity with factors and processes rather than geological features per se. For example, that areas suffering deformation during the Oligocene and Miocene are more prone to reactivation of fault structures today. Similar speculation has been raised concerning glacial isostatic recovery, forebulge collapse, and stress concentration related to interactions of crustal blocks.

The most recent national study of seismic hazard in the UK used a model based on the assumption that seismotectonic units forming areas of distinct crustal properties had to be the starting point. Where such a unit showed marked inhomogeneity in seismicity, it could be divided into “high” and “low” portions.

Biases and fragmentations in historical EQ-records: The pre-instrumental period of systematic scientific earthquake observation in Switzerland (1878–1912)

Grolimund, Remo and Donat, Fäh

Swiss Seismological Service, ETH Zurich
Sonneggstrasse 5, 8092 Zürich
remo.grolimund@gmail.com, donat.faeh@sed.ethz.ch

The period of reliable modern instrumental earthquake recording only extends back a couple of decades (1975 in Switzerland). Systematic scientific earthquake observation has, however, a longer history in Switzerland. With the establishment of the Swiss Earthquake Commission (SEC) in 1878 as the world's first permanent national organization for the observation of earthquakes, Switzerland has one of the longest-lasting continuous traditions of systematic macroseismic data-collection. The earthquakes occurring in this specific period covering the pre-instrumental [1878–1911] and early-instrumental period [1911–1963] of scientific earthquake observation are of special relevance. Due to relatively high seismicity in the pre-instrumental period and the increased production of scientific and non-scientific documentary data by the SEC, this data provide a considerable wealth of information on the earthquakes themselves and for seismic hazard assessment. Of particular interest is the seismically active region of Basel situated at the southern end of the Rhine Graben. This dataset can extend the time window of documented seismicity if it is analyzed and interpreted with historical-critical methods.

The theoretical background and presumptions, the observation methods and the organizational framework of the commission shaped the information on earthquakes documented by the SEC. These factors affect the scope and the completeness of the investigations as well as the decision making processes involved in their documentation.

In this conference paper, the biases and fragmentations of the historical earthquake data produced by the SEC will be exemplified with macroseismic information of events in the Basel area and other Swiss regions. We also compare old interpretations with reassessments of the events. In this context, the particular importance of visualization of data will be emphasized. As the commission members were actively participating in an international scientific community, a reconstruction of their "style of thinking" may be of interest to studies in historical seismology in other European countries, as well as to a general history of knowledge and science of the late 19th and early 20th century.

Estimation of magnitude-depth parameters based on automatic Isoseismal areas for XXth century selected earthquakes.

Antoine SCHLUPP

IPGS-UMR7515 and BCSF-UMS830 (UNISTRA-CNRS), 5 rue René Descartes 67084 Strasbourg.
antoine.schlupp@unistra.fr

A homogeneous seismic catalogue covering historical and instrumental period is of primary interest when dealing with seismic hazard assessment, especially in term of magnitude. This is particularly important in areas that undergo low deformation rates and low to moderate seismic activity as metropolitan France or Rhine Graben. For the depth-magnitude estimation of historical earthquakes, it is necessary to identify "proxies" in macroseismic data based on recent earthquakes.

The purpose of this work is to test the possibility to use isoseismals area, deduced from observed IDP and a numerical approach to avoid "expert interpretation impact", to characterise Moment magnitude and depth parameters for earthquakes of the XXth century. The work is based on precise instrumental parameters produced by recent work like the SI-Hex 2014 project (Cara, Cansi, Schlupp et al. 2015).

The advantages of this method are that it is independent of the epicentre location, epicentre intensity and it is not sensitive to the geometry (elongation, etc.) of the isoseismals. Nevertheless, this strategy needs to trace objectively the isoseismals. Therefore, numerical approaches are considered that can be reproducible and that reduce the uncertainties related to an expert draw or interpretation. It is finally based on adjusted parameters for local kriging interpolation.

The Isoseismals areas are converted into radius of circle of equivalent area. The method has been tested on 22 events of XXth century with Io of VII and more (MSK from SisFrance) including few in the Rhine Graben.

The plot of "radius" versus intensity appears to be a very good proxy to estimate Mw and Depth **if comparing with "master events"** that are precisely known. This permits us to avoid uncertainties on attenuation relations within the Rhine Graben area.

It seems also to be an appropriate method for depth assessment, which is one of the biggest issues for past, and even recent, seismicity.

The today's limitation in the Rhine Graben is due to data split between France, Germany and Belgium. Shared dataset will allow estimating the parameters for more events in and near the Rhine Graben.

The tests on the Rambervillers earthquake, by simulating incomplete datasets of IDP, show that lack of low intensities or large distance between observed intensities induces overestimation of isoseismal's area and of the deduced magnitude. Application to event older than the XXth century has to be done with caution and automatic draw of isoseismals on poorly know historical event seems utopian.

This work has been developed thanks to the support of the SIGMA project (WP1).

Induced seismicity in EGS reservoir: the creep route

Jean Schmittbuhl[1], Olivier Lengliné[1], François Cornet[1], Nicolas Cuenot[2] and Albert Genter[2]

[1] IPGS-UMR7515, 5 rue René Descartes 67084 Strasbourg
[2] GEIE Exploitation Minière de la Chaleur, Kutzenhausen, France

Observations in enhanced geothermal system (EGS) reservoirs of induced seismicity and slow aseismic slip ruptures on related faults suggest a close link between the two phenomena. We base our approach on the case study of the EGS site of Soultz-sous-Forêts where seismicity has been shown in particular during the 1993 stimulation to be induced not only by fluid pressure increase during stimulation but also by aseismic creeping effects. More recently a delayed sequence of seismicity four days after shut-in during the stimulation of the first well of Rittershoffen site, suggests also the development of aseismic processes in the reservoir. We propose an interpretation of the field observations of induced seismicity using a laboratory experiment that explores, in great detail, the deformation processes of heterogeneous interfaces in the brittle-creep regime. We track the evolution of an interfacial crack over 7 orders of magnitude in time and 5 orders of magnitude in space using optical and acoustic sensors. We show that a creep route for induced seismicity is possible when heterogeneities exist along the fault. Indeed, seismic event occurrences in time and space are in strong relation with the development of the aseismic motion recorded during the experiments. We also infer the statistical properties of the organization of the seismicity that shows strong space-time clustering. We conclude that aseismic processes might drive seismicity besides the classical effects related to fluid pressure and show that a creep route for induced seismicity is possible.

Limits of tectonic geomorphology techniques in the Lower Rhine Basin

Evelyn Schürmann (1), Christoph Grützner (2), Jochen Hürtgen (1), Klaus Reicherter (1)

(1) Institute of Neotectonics and Natural Hazards, RWTH Aachen University, Lochnerstr. 4-20, 52064 Aachen, Germany

(2) Bullard Laboratories, Department of Earth Sciences, University of Cambridge, Madingley Rise, Madingley Road, CB3 0EZ Cambridge, UK. chg39@cam.ac.uk

The Lower Rhine Basin is a tectonically active area characterized by very low fault slip rates. Even the most active structures move with less than 0.1 mm/yr and recurrence intervals of surface-rupturing earthquakes are in the order of tens of thousands of years. Owing to the low slip rates, geodetic techniques like levelling, GPS, and InSAR fail to measure slip rates. We tested if tectonic geomorphology techniques are successful in the Lower Rhine Basin. The calculation of geomorphic indices from digital elevation models (DEMs) can be used to evaluate vertical (tectonic) movements. Such techniques are based on analyzing drainage patterns, river profiles, drainage basin shapes and mountain morphology. The Lower Rhine Basin is a challenging area because it is slowly deforming and in an intraplate setting, where a moderate climate, mining activity, and intense agriculture rapidly modify the surface. However, its advantage is that there is a good knowledge on the location and activity of some of the active faults. In case the techniques we applied could successfully detect the known major structures, this would enable us to gather information on those which are less well investigated.

We used DEMs based on SRTM3, ASTER and airborne LiDAR data. The latter were available as pre-processed datasets of 1 m, 10 m, 25 m, and 50 m horizontal resolution. For each dataset we calculated the stream network and applied basic procedures such as hillshade analyses, shaded relief, slope angle, slope aspect, curvature, and re-classified elevation in order to detect linear features that correspond to active faults. For the lineaments we calculated the following geomorphic indices: stream length gradient index (SL), valley floor width to valley floor height ratio (Vf), asymmetric factor (Af), basin shape index (Bs), basin hypsometry (HI), and terrain ruggedness index (TRI). Our results show that ASTER and SRTM3 data lack the resolution necessary to evaluate tectonic activity. We found that the 10 m DEM can be best used for index calculations. We find that in general all indices point to no or only very little tectonic activity in the study area. Those indices that analyze the shape of drainage basins tend to work better, while those based on river shapes and mountain morphology fail to recognize the landscape as active. This rather disappointing result illustrates that there is a need for paleoseismological studies in order to gather information on the active faults in the Lower Rhine Basin, like the occurrence of the most recent large earthquakes, maximum magnitudes, fault interaction, landscape response to climate change and isostatic adjustments, surface rupture hazard, and surface rupture variability.

The Rhine Rift within the frame of the Cainozoic evolution of the Alpine foreland

A. M. Celâl Şengör

İTÜ Maden Fakültesi ve Avrasya Yerbilimleri Enstitüsü,
Ayazağa 34469 Istanbul TURKEY
sengor@itu.edu.tr

That Cainozoic deformation in Europe was not confined to the Alps, but embraced the entire continent west of the Russian Craton had been appreciated already in the third quarter of the nineteenth century. The deformation in the foreland of the Alps was likened by Eduard Suess in his epoch-making 1875 book *Die Entstehung der Alpen*, to drifting pack-ice in which internally rigid blocks move with respect to one another along shortening, extensional and transcurrent boundaries. Franz Lotze presented a rigorous kinematic analysis of this so-called *Schollentektonik* of Germany in 1937, which is identical to Wilson's presentation of plate boundaries in his classic 1965 paper on transform faults.

Of the entire block mosaic of the Alpine foreland, the Rhine Rift is the most prominent. It began rifting in the south during the Lutetian synchronusly with the onset of the Alpine collision in the Swiss Alps and extended northwards into the Hessian Trough already in the time of the deposition of the "Pechelbronn Beds" (Priabonian to Rupelian), but, by the time of the deposition of the "Niederrödern Beds", the rifting had slackened in the entire rift (lowermost Oligocene). With the beginning of the Aquitanian (Upper Cerithian and *Corbicula* Beds) we see a complete change in the rifting regime. The Upper Rhine Rift began shearing and the Aquitanian sedimentary rocks were deposited in a NW-SE-striking sub-rift. This is also the time of the initiation of the Lower Rhine Rift. The shearing of the Lower Rhine rift led to shortening in its middle section as seen in the beautiful high-angle thrust faults in quarries near Baden-Baden.

During the Eocene mafic dykes intruded the rift shoulders in the south. These dykes parallel the trend of the main Upper Rhine Rift. The vulcanicity began in the south in the Miocene (Kaiserstuhl) and propagated nortwards (Vogelsberg).

A very important observation pertains to the Eocene-early Oligacene conglomerates along the shoulders of the Upper Rpine Rift. These so-called *Küstenkonglomerate* (=coastal conglomerates) were laid down along the margins of the rift trough and contain clasts of Jurassic age in their lowest horizons. Farther up Triassic pebbles show up and finally near the top, those eroded from the crystalline basement of the Black Forest Hercynian massif. This shows that the shoulders of the rift were not high when rifting commenced! *Shoulder uplift was a syn-rifting phenomenon*.

With the Aquitanian, the Alpine Foreland began to be deformed along conjugate strike-slip faults (one set striking NNE-SSW, another NW-SE), thrust faults and folds (fault strikes and fold axes orientated ENE-WSW). All of these faults are still active, nearly all localise seismicity and almost all have been inherited from the post Hercynian structures that led to the disintegration of the Hercynian edifice in Europe. Earthquakes have repeatedly caused heavy damage, not only along the Rhine rift and its associated structures, along the thrust faults bounding the Saar-Nahe Basin, but also in Saxonia and Thüringen. (Thüringen as an example here: 1326: clearly felt around Gera, 1366: around Eisenach; many churches were destroyed; estimated M to have been 3.8)

This shows that *the entire Alpine Foreland almost to Scotland southwest of the Tornquist-Tesseyre Lineament is an active Alpide plate boundary zone.* The reason for the large width is the fact that the European lithosphere never had a chance to "recover" (i.e., cool long enough) to build a craton as the neighbouring Russian Craton did. Very similar broad plate boundary zones are well-known from Central, southern and eastern Asia and the western United States. In all these places, the reason for the breadth of the plate boundary zones is the same: lack of a substantial protective mantle lithospheric substratum.

Seismic hazard estimation of induced seismicity associated with deep geothermal energy production

Thomas Spies & Jörg Schlittenhardt

BGR, Unit 'Seismic Hazard Assessment', Stilleweg 2, 30655 Hannover

During development and operation of deep geothermal wells fracture processes can occur at different scale which are associated with induced seismicity. Cold fluid is injected into the well and heated fluid is pumped out, so that the rock is exposed to injection pressures and thermal stresses. Thus cracks may be generated or expanded which can be detected as microseismic activity using local seismometer networks. The increase of pore pressure on existing fault planes under tectonic stresses may also cause seismic events which can be felt. A similar problem exists in other industrial processes that are related to energy development and in which the pore pressure is changed, e. g. hydraulic fracturing for shale gas development, production of natural gas and crude oil and injection of liquid waste or liquid CO2.

For the planning and licensing, but also for development and operation of the wells (and plants), the impact of induced seismicity in form of possible intensities and ground motions needs to be specified. To achieve this, methods for the estimation of seismic hazard in case of natural seismicity can be modified and applied. In the research project MAGS ‚Microseismic activity of geothermal systems' funded by the German Federal Ministry of Environment (BMU) a simple model was developed to determine seismic hazard as the probability of the exceedance of ground motion of a certain size. On this basis, the procedures of standards and guidelines of construction dealing with natural seismicity and vibration phenomena could be transferred to the treatment of induced seismicity. Using limiting values from guidelines, e. g. for the feeling of seismic motion or for weak damage of buildings, it is thus possible to specify the probability of exceedance of such values and to decide whether this can be accepted or not. On the other hand the results can be compared to the impact of natural seismicity to evaluate whether the impact of induced seismicity is relevant or not.

Challenges in Assessing Seismic Hazard in Intraplate Europe

Seth Stein, Northwestern University, Evanston, IL, United States
Angela Landgraf, University of Potsdam, Potsdam, Germany
Esther Hintersberger, University of Vienna, Vienna, Austria
Simon Kuebler, LMU Munich, Munich, Germany
Mian Liu, University of Missouri, Columbia, Missouri, United States

In recent years it has been recognized that intraplate seismicity is often characterized by scattered, clustered and migrating earthquakes, the occurrence of low-strain areas next to high-strain ones, and extended aftershock sequences. A natural question is whether these observations - primarily from North America, China, and Australia - are usefully applied to seismic hazard assessment for intraplate Europe. Existing assessments are based on instrumental and historical seismicity of the past 1000 years, as well some active fault data. These observations face important limitations due to the quantity and quality of the available data bases. Even considering the long record of historical events in some populated areas of Europe, this time-span of thousand years likely fails to capture some faults typical large-event recurrence intervals that are in the order of tens of thousands of years. Paleoseismology helps lengthen the observation window, but only produces point measurements, and preferentially in regions suspected to be seismically active. As a result, the expected maximum magnitudes of future earthquakes are quite uncertain, likely to be underestimated, and earthquakes are likely to occur in unexpected locations. These issues in particular arise inconsidering the hazard posed by low-probability events, to heavily populated areas and for critical facilities like nuclear power plants. For example, the central portion of the Rhine Graben appears less active than those to the north and south, and the west side of the upper Rhine Graben appears less active than the east side.Are these differences due to short sampling or real? Could some of the seismicity we see in areas like the Vienna Basin be aftershocks of still-recognized large past earthquakes?

Magnitude overestimation or temporal variations in the Italian seismicity of the 20th century?

Massimiliano Stucchi, Eucentre Foundation, Pavia, Italy
(European Centre for Training and Research in Earthquake Engineering)

The Italian seismicity in the 20th century, as from the CPTI11 catalogue, shows a non-uniform temporal distribution. In the complete part of the catalogue - after 1870 for Mw ≥ 4.64 - the annual earthquake rate shows a rapid increase at the turn of the 20th century, with peaks between 1895 and 1905, and, later, between 1958 and 1964, together with a decrease between 1930 and 1955; moreover, the annual rates in the last 20 years are consistently lower than in the mentioned periods. If the small number of earthquake reported between 1940 and 1950 can be easily imputed to historical reasons (i.e. world-war II), the reasons of the variations in the earthquake rates for the other periods are to be understood.
Many investigators would suggest that a candidate for such a behaviour is to be found in the possible, general magnitude overestimation of the historical earthquakes, due to the presumed “arbitrariness” of historical records and their interpretation. However, a first analysis revealed that most of the fluctuation in the annual rates depends on earthquakes with 4.64 ≤ Mw < 5.11; therefore, it cannot be referred to a general “overestimation“. Moreover, it was found that Central Italy is where the variations in earthquake occurrence are most evident.
We investigated the origin of Mw values in CPTI11 which are derived from i) macroseismic data, ii) instrumental data, and iii) a combination of them (whenever the two estimates are both available), and we found that, in Central Italy, earthquakes with magnitude from Io 6, 6-7 (corresponding to the investigated lower Mw bin), account for most of the annual rates at the beginning of the 20th century. For such earthquakes, Mw has been computed from Io and not from MDPs.
We also checked whether the common assumption that macroseismic magnitudes are overestimated with respect to the instrumental ones, which are supposed to be more “objective”, holds in this case. We found that, as a general trend, in the first half of the 20th century, instrumental Mw values derived from the conversion of early instrumental magnitudes (mostly Ms), exceed the corresponding macroseismic magnitude.
So, we conclude to date that the time variations in the earthquake rates in Italy in the 20th century:

- derive from low magnitude events (4.64 ≤ Mw < 5.11);
- prevail in Central Italy;
- are mostly due to earthquakes not supported by MDPs distributions for which Mw derives from Io = 6, 6-7.

A possible explanation for that is the CPTI catalogues, although having incorporated the results of many historical-macroseismic recent studies, also relies on previous catalogues, compiled for the nuclear power investigations. In this phase (70’s) the compilers used a “safe” approach, translating the occurrence of a “strong” earthquake in the historical records into Io = 6. Central Italy contains most of such earthquakes. A preliminary check with the “in progress” version of the CPTI catalogue, where for those earthquakes magnitude has been determined from MDPS, seems to drastically modify the investigated trend.
So the conclusion is that, yes, there could be some episodes of magnitude “overestimation”, but they are rather limited and have a specific reason. On the other hand, temporal variation in the catalogue may reflect true seismicity fluctuations, as also suggested also by expanding this investigation to other regions of Europe.

Normal fault systems and associated earthquakes along the axial zone of the Apennines (Italy)

Emanuele Tondi
Geology Division, School of Science and Technology, University of Camerino, Italy
E-mail: emanuele.tondi@unicam.it

The Apennines are part of a post-collisional segment of the Mediterranean Africa-vergent mountain system which is made up of several tectonic units emplaced, since the Oligocene, as a result of convergence and collision between the continental margins of the Corsica-Sardinia block (of European origin) and of the Adriatic block (of African affinity). The high-topography zone of the Apennines is dissected by Quaternary fault systems, overprinting and/or inverting older structures of the fold and thrust belt. These faults, bounding and controlling the evolution of several intermontane basins in-filled by fluvio-lacustrine sediments, are predominantly of extensional type and their development and evolution has been related to crustal thinning processes occurring in the Tyrrhenian area.

In the last few years, some of these late faults have been investigated in great detail by means of morphotectonic and structural analysis of exposed fault scarps. Evidence for their recent activity is provided by faulted Middle Pleistocene-Holocene deposits (including 30-40 ka old pyroclastites and 40 ka old palustrine sediments), fresh scarps in both bedrock and late Quaternary continental deposits, and decametric offsets locally affecting the Post-Wurmian drainage pattern of the area. These faults are responsible of a diffuse seismicity distributed within a NNW-SSE trending, 40-50 km wide zone, along the Apennines. Recently, few events, occurred within the high-topography zone of this main seismic belt, show maximum intensities in the range of 10-11 degree MCS and magnitudes between 6.0 and 6.9. Among these, particularly interesting for their highly destructive effects recorded over a large area are, from North to South: a) The 1997 Umbria-Marche earthquake (Mw=6.0); b) the 2009 L'Aquila earthquake (Mw=6.3); c) The 1979 Irpinia Earthquake (Mw=6.9). Thanks to the seismotectonic information provided by these recent earthquakes, was possible to better interpret, in terms of seismogenic potential, the active faults outcropping along the axial zone of the Apennines, providing new constraints for seismic hazard assessment in peninsular Italy.

Simulation of Mmax distributions for superdomains in stable continental regions

Kris Vanneste[1], Bart Vleminckx[1], Seth Stein[2] & Thierry Camelbeeck[1]
[1] Royal Observatory of Belgium, Ringlaan 3, B-1180 Brussels, Belgium, email: kris.vanneste@oma.be
[2] Northwestern University, 2145 Sheridan Road, Evanston, IL 60208-3130, USA

The Bayesian Mmax approach (EPRI, 1994; U.S. Nuclear Regulatory Commission et al., 2012) is often used in probabilistic seismic hazard assessment (PSHA) to define the maximum magnitude, the upper truncation of the magnitude-frequency distribution (MFD), in distributed-seismicity sources. In this approach, a global prior distribution on Mmax was established for stable continental regions (SCR) based on magnitudes of earthquakes observed worldwide within tectonically similar domains, grouped into so-called superdomains. This prior distribution is then multiplied with a source-specific likelihood function that depends on the largest magnitude and the number of earthquakes observed in the source, to obtain a posterior distribution on Mmax that is treated as epistemic uncertainty in PSHA. However, in many SCR areas the sample size is low, making the posterior distribution strongly dependent on the Mmax prior. The choice of the prior distribution is thus critical. We question the nature of the observed superdomain Mmax distribution that was used to derive the Mmax prior, and test if this distribution could also be explained by a uniform global Mmax value, given the limited periods of observation (catalog lengths) that we are coping with in SCR. For this purpose, we generate random catalogs for SCR domains based on the assumption that seismicity in a domain is represented by a doubly truncated Gutenberg-Richter MFD and follows a Poisson distribution. For each SCR domain, an MFD is constructed with a lower bound of M=4.5 and an upper bound equal to the considered parent Mmax, and with the a- and b-values reported for the corresponding continent (EPRI, 1994), but scaled according to the domain area. The start year and completeness thresholds of each catalog are obtained by manually assigning the corresponding domain to one of the completeness regions in EPRI (1994). We simulate 10,000 synthetic catalogs for each SCR domain, combine them into superdomain catalogs, and determine the largest sampled magnitude and the number of sampled earthquakes in each. With a parent Mmax of 7.9 (largest magnitude observed in SCR), and catalogs ending in 2008 (end year of CEUS SCR catalog), we obtain superdomain Mmax distributions that appear very similar to the one observed. The overall mean sampled Mmax and the average standard deviation are very close to the actually observed values. This is also the case for the average minimum sampled Mmax. This good agreement indicates that a global uniform Mmax of 7.9 in SCR cannot be ruled out at present. We also investigate the effect of larger parent Mmax and longer catalogs. Our results confirm that catalog length is indeed the limiting factor in our knowledge of Mmax.

EPRI, 1994, The Earthquakes of Stable Continental Regions. Volume 1: Assessment of Large Earthquake Potential: Electric Power Research Institute.

U.S. Nuclear Regulatory Commission, U.S. Department of Energy, and Electric Power Research Institute, 2012, Central and Eastern United States Seismic Source Characterization for Nuclear Facilities:.