FAULT2SHA
WORKING GROUP

FAULT COMPLEX INTERACTION:

Characterization and Integration into Seismic Hazard Assessment (SHA)

Institut Ciències del Mar - CSIC
Barcelona 3rd-5th June 2019

Pre-Workshop Proceedings. Version 3 (final).

Host organizing committee

University of Barcelona (UB): María Ortuño, Eulàlia Masana, Octavi Gómez-Novell, Gia Kzhazaradze, Robert López, Raimon Pallàs

Institute of Marine Sciences (ICM-CSIC): Eulàlia Gràcia, Hèctor Perea, Rafa Bartolomé, Cesar Ranero

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1 - PROGRAM

The workshop is organized in three thematic sessions and a trans-disciplinary round table. Each session include invited keynote lectures (45+15 minutes), few regular talks (10+5 minutes), some flash talks (3+2 minutes), and posters. All the participants are invited to prepare a poster that will be available for the whole duration of the workshop, to facilitate discussions and interactions. Some suggestions for flash talk format and poster templates are given in the Appendix. The pre-workshop program is as it follows.

JUNE 3, MONDAY

Arrival of participants during the morning.

11:00 – 12:30 Registration at the venue

12:30 – 14:00 *Lunch (included in the registration fee) at* ***Marina Bay restaurant***

14:00 – 14:30 Welcome and opening of the workshop
(ESC President, ICM President, Fault2SHA Coordinators)

SESSION 1: The EBSZ (SE Spain) lab: advances in earthquake geology research and seismic hazard modelling

14:30 – 15:30 Invited keynote Lecture, IL 1.1
Advances and Challenges in Fault-hazard Modelling in the Eastern Betics Zone
by: **Eulalia Masana (Univ. Barcelona) & Belén Benito (Univ. Politécnica de Madrid)**

15:30 – 16:30 Flash Talks Session 1

1) **FT/PO 1.1** ARCHITECTURE AND DETAILED KINEMATIC ANALYSIS OF THE FAULT ROCK OF THE ALHAMA DE MURCIA FAULT (SE IBERIA) by: Jorge Alonso-Henar, Carlos Fernández, José Jesús Martínez-Díaz, Emilio Rodríguez-Escudero, Juan Miguel Insua Arévalo, Carolina Canora Catalán, Paula Herrero-Barbero, José Luis Sánchez Roldán, José Antonio Álvarez-Gómez, Yolanda de Pro Díaz
2) **FT 1.3** TSUNAMIGENIC RISK ASSOCIATED TO VERTICAL OFFSET IN TRANSCURRENT FAULT TERMINATION: THE CASE OF THE AVERROES FAULT (ALBORAN SEA) by: Estrada, F., González-Vida, J.M., Peláez, J.A., Galindo-Zaldívar, J., Ercilla, G., Vázquez, J. T.
3) **FT 1.4** THE AL HOCEIMA SEISMIC ZONE (SW PROLONGATION OF THE EBSZ IN THE RIF): GPS EVIDENCES OF DEEP TECTONIC DISPLACEMENTS ON A MAIN ACTIVE BLIND SINISTRAL FAULT by: Jesús Galindo-Zaldívar, Antonio J. Gil, Omar Azzouz, Gemma Ercilla, Alberto Sánchez-Alzola, María C. de Lacy-Pérez de los Cobos, Antonio M. Ruiz-Armenteros, Said Bengamra, Ferrán Estrada, Patricia Ruano and Mohamed Makkaoui
4) **FT/PO 1.5** FIRST PALEOSEISMIC EVIDENCE OF THE FRONTAL BRANCH OF ALHAMA DE MURCIA FAULT ZONE (EASTERN BETICS, SE SPAIN) AND ITS HOLOCENE ACTIVITY by: Octavi Gómez-Novell, Maria Ortuño, Julián García-Mayordomo, Eulàlia Masana, Thomas Rockwell, Stéphane Baize, Robert López, Albert Baguer
5) **FT/PO 1.7** SLIP RATE DISTRIBUTION ALONG THE NORTHERN TERMINATION OF THE ALHAMA DE MURCIA FAULT by: Paula Herrero-Barbero, José Antonio Álvarez-Gómez, José Jesús Martínez-Díaz

6) **FT 1.9** GEODETIC SLIP PARTITIONING BETWEEN THE ALHAMA DE MURCIA AND PALOMARES FAULTS IN THE SE BETICS, SPAIN by: G. Khazaradze, A. Staller, R. López, J. J, Martínez-Diaz, E. Masana

7) **FT/PO 1.10** REFINING SEISMIC PARAMETERS OF THE CARBONERAS FAULT (SE IBERIA) FROM LATE PLEISTOCENE TO EARLY HOLOCENE AT TOSTANA SITE by: Robert López, Eulàlia Masana, Giorgi Khazaradze, Octavi Gomez-Novell, Raimon Pallàs, María Ortuño, Stéphane Baize, Thomas Rockwell

8) **FT 1.13/PO** SEISMOGENIC SOURCE OF THE 1919 TORREMENDO EARTHQUAKE by: Iván Medina-Cascales, Pedro Alfaro and Iván Martín-Rojas

9) **FT/PO 1.14** THE 2011 MW 5.2 LORCA EARTHQUAKE AS A CASE STUDY TO INVESTIGATE THE GROUND MOTION VARIABILITY RELATED TO THE SOURCE MODEL by: Luca Moratto, Angela Saraò, Alessandro Vuan, Marco Mucciarelli, María José Jiménez, Mariano García-Fernández

10) **FT 1.18** NNE-SSW LEFT-LATERAL ACTIVE FAULTS IN THE MOTRIL-DJIBOUTI MARGINAL PLATEAU, NORTHERN MARGIN OF THE ALBORAN SEA (WESTERN MEDITERRANEAN) by: J.T. Vázquez, F. Estrada, E. Ercilla, E. D'Acremont, J. Galindo-Zaldívar, D. Palomino, B. Alonso, C. Juan, Ch. Gorini and R. Vegas

16:30 – 17:00 *Coffee Break*

17:00 – 18:00 Invited keynote Lecture, IL 1.2

2016 Kaikōura Earthquake: Reflections and Lessons learnt
by: **Kelvin Berryman (GNS Science, New Zealand)**

18:00 – 18:30 Regular Talks Session 1

I. **RT 1.6** SEISMIC CRISIS REVEALS THE DEVELOPMENT OF AN INCIPIENT CONTINENTAL FAULT SYSTEM IN THE ALBORAN SEA by: Eulàlia Gràcia, Ingo Grevemeyer, Rafael Bartolomé, Hector Perea, Sara Martínez-Loriente, Laura Gómez de la Peña, Antonio Villaseñor, Yann Klinger, Claudio Lo Iacono, Susana Diez, Alcinoe Calahorrano, Miquel Camafort, Sergio Costa, Elia d'Acremont, Alain Rabaute and César R. Ranero

II. **RT 1.11** FORWARDS AND BACKWARDS BETWEEN FIELD DATA AND SEISMIC HAZARD ANALYSIS: THE BAZA FAULT by: Iván Martín-Rojas, José Antonio Peláez, Iván Medina-Cascales, Francisco Juan García-Tortosa, Pedro Alfaro

18:30 – 19:30 Posters Session 1 & Interaction (**NOTE**: posters from sessions 2 and 3, as well as companion posters from flash talks, should have been already hung on their corresponding slot by this time)

- **PO 1.2** SEISMIC HAZARD SCENARIOS THROUGH DIFFERENT MODELING OF THE CARBONERAS FAULT AND ITS IMPACT ON THE EXPECTED GROUND MOTION IN THE CITY OF ALMERIA by: Benito Oterino, MB; Rivas Medina, A., Gaspar-Escribano, J. and Staller, A.

- **PO 1.8** CHALLENGES FOR THE ESTIMATION OF THE SEISMIC POTENTIAL IN AREAS OF DISTRIBUTED DEFORMATION: THE CASE OF THE AREA BETWEEN THE PALOMARES AND CARRASCOY FAULTS (EASTERN BETIC SHEAR ZONE, SE IBERIA) by: J.M. Insua-Arévalo, J. García-Mayordomo, J.L. Sánchez-Roldán, O. Gómez-Novell, S. Baize, H. Jomard, J.J. Martínez-Díaz, C. Canora-Catalán, P. Herrero-Barbero, R. López-Escudero, E. Masana

- **PO 1.12** ACTIVE TECTONICS, CRUSTAL STRUCTURE AND AFFINITY OF THE BASEMENT DOMAINS OFFSHORE SW IBERIA. REGIONAL GEODYNAMIC IMPLICATIONS OF THE AFRICA-EURASIA PLATE BOUNDARY by: Sara Martínez-Loriente, Valentí Sallarès, Eulàlia Gràcia
- **PO 1.15** IMPACT OF THE FAULTS MODELING IN PROBABILISTIC SEISMIC HAZARD ASSESSMENT (PSHA) IN SOUTH AND SOUTHEASTERN CITIES OF SPAIN by: Rivas Medina, A; Benito Oterino, MB; Gaspar-Escribano, J.
- **PO 1.16** SEISMIC HAZARD IMPLICATIONS OF THE INTERNAL STRUCTURE OF THE ALHAMA DE MURCIA FAULT (SE SPAIN) by: Emilio Rodríguez-Escudero, José J. Martínez-Díaz, André R. Niemeijer, Meaza Tsige, Jorge L. Giner-Robles, Jorge Alonso-Henar, J. Miguel Insua-Arévalo, J.A. Álvarez-Gómez
- **PO 1.17** EASTERN GUADALQUIVIR BASIN SEISMICITY RELATED TO STRIKE-SLIP FAULTING: GEODYNAMICS IMPLICATIONS IN THE EASTERN BETIC CORDILLERA by: Víctor Tendero-Salmerón, Jesús Galindo-Zaldívar, José A. Peláez, Manuel Martínez-Martos, Jesús Henares, Carlos Marín-Lechado, Antonio J. Gil, Ángel Carlos López-Garrido

JUNE 4, TUESDAY

SESSION 2: Earthquake fault rupture and slip complexities: How-To OBSERVE them from field data

08:30 – 9:30 Invited keynote Lecture, IL 2.1

Observation of Fault Complexity from Recent Earthquakes
by: **Tom Rockwell (San Diego State University, USA)**

9:30 – 10:30 Flash Talks Session 2

1) **FT 2.4** IMPROVING THE KNOWLEDGE OF FAULTS 4 SOUTHERN APENNINES SHA: THE SOUTHERN MATESE NORMAL FAULTS (ITALY) by: Paolo Boncio, Eugenio Auciello, Vincenzo Amato, Pietro Aucelli
2) **FT 2.9** SLOW SLIP RATE AND LONG RETURN PERIOD OF LARGE EARTHQUAKES IN THE TRACE OF THE 1967 M7 MOGOD EARTHQUAKE (MONGOLIA) by: Y. Klinger, L. Bollinger, S. Forman, O. Chimed, A. Bayasgalan, U. Munkhuu and G. Davaasuren
3) **FT/PO 2.10** NEW OBSERVED EVIDENCE OF ACTIVE FAULTING IN AN OFFSHORE FORELAND REGION: THE SOUTH APULIA FAULT SYSTEM by: Maesano F.E., Volpi V., Civile D., Conti A., Accettella D., Tiberti M.M., Conte R., Zgur F., Basili R., Rossi G.
4) **FT 2.11** COMPLEXITY IN INTRAPLATE ACTIVE FAULT GEOMETRIES: IMPLICATIONS FOR SEISMIC HAZARD by: F. Martín-González and N. Heredia
5) **FT 2.12** EVIDENCING COMPLEX FAULT RUPTURES BY BAYESIAN STATISTICAL ANALYSIS OF PALAEO-EARTHQUAKES. COULD THE 2016 KAIKŌURA EARTHQUAKE HAVE PROPAGATED FURTHER NORTH? By: Iván Martin-Rojas, Juan Miguel Insua-Arévalo, Pilar Villamor, Fidel Martín González, José Jesús Martínez-Díaz, Robert M. Langridge, Russ J.Van Dissen
6) **FT/PO 2.13** FAULT RELAY ZONES WITHIN THE TERUEL GRABEN SYSTEM (EASTERN IBERIAN CHAIN): GEOMETRIES, INTERACTIONS AND SEISMOLOGICAL IMPLICATIONS by: Alba Peiro, José Luis Simón y Teresa Román-Berdiel
7) **FT 2.14** FAULT AND FOLD SEGMENTATION AND COMPLEXITY: NEW INSIGHTS FROM 3D P-CABLE DATA OFFSHORE SOUTHERN CALIFORNIA by: Hector Perea, James Holmes and Neal Driscoll

8) **FT 2.16** POST-SEISMIC DEFORMATION FOLLOWING THE 2016 NORCIA EARTHQUAKE (ITALY), AS REVEALED BY INSAR TIME SERIES by: Léa Pousse-Beltran, Anne Socquet, Lucilla Benedetti, Marie-Pierre Doin, Magali Rizza, Nicola D'Agostino

9) **FT/PO 2.17** TSUNAMIGENIC STRUCTURES IN THE GULF OF CADIZ AND THE WORKFLOW FOR TSUNAMI HAZARD ASSESSMENT by: C.S. Serra, E. Gràcia, R. Urgeles, S. Martínez-Loriente, L. Gómez de la Peña, S. Lorito, A. Piatanesi, F. Romano, F. Maesano, R. Basili and M. Volpe

10) **FT/PO 2.18** INTRAPLATE LATE QUATERNARY TECTONIC ACTIVITY OF THE MARIÁNSKÉ LÁZNĚ FAULT (CHEB BASIN, CZECH REPUBLIC) DOCUMENTED ON A SITE WITH SURFACE FAULT COMPLEXITY by: Petra Štěpančíková, Tom Rockwell, Tomáš Fischer, Filip Hartvich, Petr Tábořík, Jakub Stemberk, Hamid Sana, Lucie Nováková

10:30 – 11:15 *Coffee Break*

11:15 – 12:00 Regular Talks Session 2

I. **RT 2.1** NEAR-FAULT VARIATIONS OF SLIP AND STRAIN FOR A COMPLEX RUPTURE ZONE OF THE BALUCHISTAN EARTHQUAKE (PAKISTAN, 2013) by: Solène Antoine, Yann Klinger, Arthur Delorme, Ryan Gold, Elwina Rupnick and Marc Pierrot-Deseilligny

II. **RT 2.7** CHANGES IN CO-SEISMIC THROW AND SLIP AT FAULT BENDS AND FAULT SCALING RELATIONSHIPS by: Joanna Faure Walker, Francesco Iezzi, Zoë Mildon, Gerald Roberts, Huw Goodall, Maxwell Wilkinson, and Jennifer Robertson

III. **RT 2.8** MOVING TOWARD THE OBSERVATION OF A FULL SPECTRUM OF FAULT RUPTURE MODES: A DREADFUL SPECTRE FOR MODELERS? by: Ferrario M.F., Livio F., Michetti A.M.

SESSION 3: Earthquake fault rupture and slip complexities: How-To MODEL them in SHA

12:00 – 13:00 Invited keynote Lecture, IL 3.1

Causes and ways for modelling complexity in SHA
by: **Bruno Pace (Università degli Studi G. d'Annunzio Chieti e Pescara, Italy)**

13:00 – 14:30 *Lunch (included in the registration fee) at* ***Marina Bay restaurant***

14:30 – 15:15 Regular Talks Session 3

I. **RT 3.3** REDUCING UNCERTAINTIES IN SEISMIC RISK ESTIMATES IN ISTANBUL BY COMBINING STATISTICS- AND PHYSICS-BASED APPROACHES by: Thomas Chartier, Oona Scotti, Hélène Lyon-Caen, Keith Richards-Dinger, Jim Dieterich, Aurélien Boiselet

II. **RT 3.14** AN UNSEGMENTED WASATCH FAULT ZONE MODEL: IMPACT ON PROBABILISTIC SEISMIC HAZARD ANALYSIS by: Alessandro Valentini, Christopher B. DuRoss, Bruno Pace, Ryan D. Gold, Francesco Visini, Richard W. Briggs, and Edward H. Field

III. **RT 3.18** A MULTI-CYCLE EARTHQUAKE SIMULATOR FOR PROBABILISTIC EARTHQUAKE RUPTURE FORECASTING by: Olaf Zielke, Martin Mai

15:15 – 16:15 Flash Talks Session 3

1) **FT 3.1** MODELING SEISMIC HAZARD OF SUBDUCTION ZONES: THE CASE OF THE CALABRIAN ARC, ITALY by: Basili Roberto, Maesano Francesco Emanuele, Tiberti Mara Monica, Visini Francesco (INGV, Italy)
2) **FT 3.4** IMAGINING THE LARGEST TECTONIC EARTHQUAKES ON EARTH by: Á. González
3) **FT 3.5** IMPROVEMENT OF SEISMIC HAZARD ASSESSMENT FOR NORTHERN ALGERIA BASED ON FAULT PARAMETERS MODELING by: M. Hamdache, A. Yelles Chaouche and J. A. Pelaez
4) **FT 3.6** USING GPS DATA TO CONSTRAIN MAXIMUM MAGNITUDE IN SUPER-SLOW DEFORMATION REGIONS by: M. Jacottin, S. Mazzotti, O. Scotti
5) **FT/PO 3.7** PROBABILISTIC SEISMIC HAZARD ASSESSMENT FOR THE SUBDUCTION INTERFACE IN ECUADOR: EXPLORATION OF ALTERNATIVE SOURCE MODELS AND IMPACT ON HAZARD ESTIMATES by: J. Mariniere, C. Beauval, J.-M. Nocquet, H. Yepes
6) **FT 3.8** GEOLOGIC VERSUS GEODETIC SLIP RATE: THE CASE OF MARSICANO FAULT, CENTRAL APENNINES by: Miccolis S., Carafa M. M. C., Di Lorenzo C., Kastelic V., Di Naccio D.
7) **FT/PO 3.9** PROBABILISTIC FDH MAPS FOR THRUST FAULTS: MODELLING BASED ON NEW EMPIRICAL REGRESSIONS FOR DISTRIBUTED FAULTING by: Fiia Nurminen, Francesco Visini, Bruno Pace, Alessandro Valentini, Paolo Boncio
8) **FT/PO 3.11** SEISMIC HAZARD COMPUTED FOR CENTRAL ITALY COMBINING BOTH PROBABILISTIC AND DETERMINISTIC APPROACHES by: Santulin M., Moratto L., Tamaro A.
9) **FT 3.15** FRESH: AN APPROACH FOR COMPUTING EARTHQUAKE RUPTURES AND RATES OF OCCURRENCES IN FAULT SYSTEMS by: Francesco Visini
10) **FT 3.16** ANALYSIS OF THE SEISMIC SERIES FOLLOWING THE LARGE THRUST EARTHQUAKE OF 18 APRIL 2014, PAPANOA, MEXICO (M7.3) by: Pouye Yazdi, Jorge M Gaspar-Escribano, Miguel A Santoyo

16:15 – 17:00 *Coffee Break*

17:00 – 18:30 Posters Session 2 & Interaction (all posters should have been hung on their corresponding slot on the first day, including companion posters from flash talks)

- **PO 2.2** THE 2018 MW4.9 ETNA EARTHQUAKE: HOW FAULT RUPTURE FITS SHA BASED ON GEOLOGIC APPROACHES by: R. Azzaro and the EMERGEO Working Group (Emergenza Etna 2018)
- **PO 2.3** A WORLDWIDE AND UNIFIED DATABASE OF SURFACE RUPTURES (SURE) FOR FAULT DISPLACEMENT HAZARD ANALYSES by: Baize, S., Nurminen, F., Sarmiento, A., Dawson, T., Takao, M., Scotti, O., Azuma, T., Boncio, P., Champenois, J., Cinti, F. R., Civico, R., Costa, C., Guerrieri, L., Marti, E., McCalpin, J., Okumura, K., Villamor, P.
- **PO 2.5** ACTIVE TECTONICS RELATED -GEOMORPHIC AND GEOLOGICAL FEATURES IN THE LOWER CHELLIF BASIN (TELL ATLAS, ALGERIA) by: Y. Bouhadad
- **PO 2.6** SOURCE PARAMETERS AND COULOMB STRESS ANALYSIS FOR INTERACTED ADJACENT FAULT SEGMENTS IN NORTHEASTERN ALGERIA by: Oualid Boulahia, Abdelkarim Yelles-Chaouche, Issam Abacha, Hamoud Beldjoudi
- **PO 2.15** MARCA-GEHN, A PROTOTYPAL MACROSEISMIC ARCHIVE OF FOUR CENTRAL AMERICA COUNTRIES by: Laura Peruzza, Eliana Esposito, Giuseppe Giunta, Griselda Marroquín, Rosa Amelia García Castro, Rodolfo Torres, Douglas Antonio Hernandez, Sara Guevara, Edwin Nadir Castrillo, Carlos Rubi Tellez,

David Monterroso, Pablo Santos, Tanya Ordóñez Martínez, Félix Enrique Rodríguez García, Maynor Ruiz, Carlos Tenorio, Abel Alexei Argueta Platero, Omar Flores, Alan Cosillo, Amilcar Roca, Claudio Cravos

- **PO 2.19** PARAMETERISING SEISMIC HAZARD IN REGIONS WITH LITTLE HISTORICAL OR INSTRUMENTAL SEISMICITY: LESSONS FROM DEVELOPING THE MALAWI RIFT ACTIVE FAULT DATABASE by: Jack N Williams, Åke Fagereng, Luke NJ Wedmore, Juliet Biggs, Lachlan Wright, Donna Shillington, Christopher Scholz, Felix Mphepo, Zuze Dulanya, Hassan Mdala, Katsu Goda, Berhe Goitom

17:00 – 18:30 Posters Session 3 & Interaction (all posters should have been hung on their corresponding slot on the first day, including companion posters from flash talks)

- **PO 3.2** IS IT AN ADDED-VALUE TO ASSESS PSHA USING DETERMINISTIC PHYSICS-BASED MODELS OR IT IS THE SAME IF USING GMPES BASED ON THE SAME MODELS? BY: A. Carvalho
- **PO 3.10** TOWARD A FAULT2SHA COST ACTION by Peruzza, L.
- **PO 3.12** FAULT2SHA by: Oona Scotti and Fault2SHA Executive Committee
- **PO 3.13** FAULT-BASED PROBABILISTIC SEISMIC HAZARD ASSESSMENT (PSHA) IN EXTENSIONAL AND COMPRESSIONAL TECTONIC SETTINGS: EMPHASIS ON COMPLEX SOURCE GEOMETRY AND ACTIVITY RATE CHARACTERIZATION by: Syed Tanvir Shah, A. Arda Özacar and Zeynep Gülerce

21:00 *Social Dinner (included in the registration fee) at* ***Pomarada restaurant***

JUNE 5, WEDNESDAY

ROUND TABLE: Earthquake supercycles and earthquake conversations

08:30 – 10:30 Round Table
Earthquake supercycles and earthquake conversations
Lead by: **Lucilla Benedetti (CEREGE, France), Julián García-Mayordomo (IGME, Spain) and Marco Pagani (GEM, Italy)**

10:30 – 11:30 *Coffee Break*

11:30 – 13:30 Wrap up of the workshop
Discussion on Fault2SHA next steps (workshop, ESC General Assembly, COST & ITN funding proposals)
Farewell

13:30 – 14:30 *Lunch (included in the registration fee) at* ***Marina Bay restaurant***

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2 - ABSTRACTS

Abstracts of invited lectures (**IL**, 60 minutes including discussion), regular talks (**RT**, 15 min max), flash talks (**FT**, 5 min max), and poster presentations (**PO**) are collected here. Those flash talks that have a companion poster are coded as **FT/PO**. The invited lectures will be available on the workshop webpage http://fault2sha.net/4th-workshop/ after the meeting. Participant contributions are subdivided in the three sessions, and listed in alphabetical order. Please note that all the authors are asked to summarize their topics in a poster, to facilitate informal discussion. Posters will eventually be available online after the meeting too.

INVITED LECTURES

IL 1.1 - Advances and Challenges in Fault-hazard Modelling in the Eastern Betics Zone, by Eulàlia Masana and Belén Benito

The Eastern Betic Shear Zone, composed by a system of left-lateral/reverse faults (from north to south: Bajo Segura, Carrascoy, Alhama de Murcia, Palomares and Carboneras faults), largely absorbs the shortening between Iberia and Africa in the Iberian side. After several years of paleoseismic studies in the area we now have strong evidence of the seismogenic nature of the system. However, new questions arise on: i) the seismic parameters of each fault and their precision, and ii) how to use this data to enhance the seismic hazard models. Here, we list some of the achievements and limitations. The left-lateral and reverse kinematics of these faults is proved as well as their geometry based on surface data, less information is available about the subsurface geometry of most of them. The first robust slip-rate values obtained from geomorphology, 3D trenching and dating (i.e. around 1 mm/yr in Alhama de Murcia fault), or from geomorphology and high-resolution offshore seismics and bathymetries (Carboneras fault, 1.3 mm/yr) are surprisingly high, but still, coherent with the GPS data. Slip-rate values are available for some of these faults (and even for different segments), but not all of them concern the Holocene. Very long sequences of earthquakes have been obtained in some faults (i.e. in the Alhama de Murcia fault at Goñar, with 6 events in more than 300 kyr of history, or at El Saltador site with10 events in the last 100 ka), but they likely correspond to a minimum as the sedimentation is not continuous and, therefore, the estimated recurrences are maximum values. The proposed segmentation of the system and the different faults has not yet been validated by paleoseismic studies, as dating resolution is not precise enough to bracket the events, therefore, the estimation of the maximum magnitudes based on segment length is still uncertain. On the other hand, very valuable information has been recently obtained concerning the elapsed time, as there is geological evidence of the last event in 3 independent sites. In addition, the slip per event was also estimated and might yield an independent approximation to the Maximum magnitude. After the knowledge acquired in recent years about the geometry and kinematics of faults, we now consider the challenge of how to optimize it to improve seismic hazard estimates, including the quantification of its uncertainty. Some key questions that have been raised in this regard are: How to model faults as independent seismic sources and how to combine them with zoning models? How to distribute the seismic potential between zones and faults in hybrid models? Is it possible (or not) to include temporal dependence on the recurrence? How to contemplate possible segmentation and coupling in faults? These issues will be presented for discussion and some resolution proposals will be formulated. The sensitivity of different proposed solutions in hazard results will be also analyzed.

IL 1.2 - 2016 Kaikōura Earthquake: Reflections and Lessons learnt, by Kelvin Berryman

Widespread surface rupture, ground motions exceeding 1g, landslides and other ground failures, and a tsunami were physical features of the 2016 Mw7.8 Kaikōura earthquake. This was primarily a rural earthquake and in many ways in stark contrast to the devastating Canterbury earthquakes of 2010-2011. Compared with Canterbury the Kaikōura aftershock sequence was very compressed which has seen all the major aftershocks (so far) occurring within the first 14 hours of the mainshock. The scarcity of large aftershocks after the initial flurry has been a major benefit to the ability to re-open the transport corridor along the Kaikōura coast. It was certainly unusual that 24 faults ruptured simultaneously in north Canterbury and Marlborough, but we now understand that several of these faults were named separately but are now known to be continuous. Also, all large (magnitude 7.5 and more) are invariably complex so while it is important to learn as much as we can from the complexity approximately 80% of the moment release was on the Jordan-Kekerengu-Needles fault and this was a probable event in terms of slip and likelihood.

Another unusual feature of the Kaikōura quake were the strong ground motions experienced on soft soil sites in Wellington. This was because of the direction and style of rupture which directed a 'beam of strong seismic energy' towards Wellington where the largest insured losses occurred. The largest social impacts were in smaller settlements that became isolated, on agricultural production and on loss of regional tourism and associated businesses in the epicentral region. Coming relatively soon after the Canterbury earthquake sequence meant that many relationships – with media, civil protection, response and recovery agencies and with local government and central government officials and politicians – were effectively and easily reactivated. The integration between GeoNet data providers and modellers worked effectively so that advice was provided reasonably quickly and effectively to decision-makers. While GNS coordinated most of the science response many other research groups were also engaged in the wider team effort. In hindsight the coordination between physical scientists and engineers could be improved through more integrated advice and data sharing. The Kaikoura event served as an important 'stress test' of the science response plan for anticipated even larger earthquakes on the Alpine Fault and the Hikurangi subduction zone.

IL 2.1 - Observations of Fault Complexity from Recent Earthquakes, by Tom Rockwell

Large earthquakes commonly produce rupture to the ground surface and the surface displacements can be characterized a number of classical and modern techniques. Many plate-boundary ruptures have been relatively simple, with most or all of the displacement localized on the main fault that produced the earthquake. In contrast, many recent earthquakes have occurred on minor (low slip rate) faults that have produced complex ruptures. Complex fault ruptures typically include multiple faults, including conjugate and splay faults, in addition to the primary rupture. Many of these secondary ruptures were likely overlooked in early characterizations of fault ruptures as early efforts typically involved field mapping of surface ruptures (crack mapping) with or without the aid of aerially photography. As the mapping may have involved weeks of field time, many secondary ruptures were likely missed or had been eroded by the time geologists actually made it to the field. Modern techniques involve a combination of rapid collection of aerial photography, LiDAR and InSAR from which to both locate the primary and secondary ruptures and make initial estimates of displacement. In California, new techniques have been applied to several recent earthquakes. InSAR was first applied to the 1992 Landers earthquake rupture, and it was evident that several minor faults had been missed in initial field mapping. Thankfully, high-resolution aerial photography allowed for the capture and mapping of many secondary faults months after the earthquake. LiDAR was flown soon after the 1999 Hector Mine earthquake and illuminated many offsets that were missed in the field mapping that immediately followed the earthquake. CosiCor (optical image correlations) was critical in locating the primary fault trace in steep topography that experienced massive slope instability in the 2010 M7.3 El Mayor-Cucapa earthquake. New applications also include the flying of unmanned aerial vehicles (UAVs, or drones) immediately after an earthquake to capture short-lived geomorphic features that may disappear in a major storm. All of these methods are now standard techniques following a major earthquake in southern California.

IL 3.1 - Causes and ways for modelling complexity in SHA, by Bruno Pace

Probabilistic fault-based and time-dependent seismic hazard studies are commonly used to forecast the time between consecutive earthquakes; however, the fault segmentation model and the slip rate variability over time are critical for obtaining accurate results. Recent complex coseismic ruptures (e.g., 2010 Mw 7.1 Canterbury, 2012 Mw 8.6 Sumatra, 2016 Mw 7.8 Kaikōura, 2016 Mw 6.5 central Italy) have shown the need to consider different possible combinations of rupture scenarios. Moreover, geological and paleoseismological observations confirm the slip rate variability, but rarely seismic hazard models consider it. A possible explanation is the presence of networks of active faults, which interact in a complex manner. Here we present the results of some studies we have done on these topics. In terms of fault segmentation relaxation, we compare different methodologies to obtain fault-based seismic hazard estimates using several rupture scenarios combinations. In term of fault interaction, we show the importance considering the time-dependent viscoelastic relaxation of the lower crust and upper mantle as a possible additional source of stress changes at a regional scale to explain the concatenation of moderate-to-strong earthquakes. We present also some insights on the coefficient of variation of the recurrence time using a simple earthquake simulator, as suggestion on how geometrical and physical parameters in a fault network may control the seismicity behavior. In addition to the development of realistic fault models (comprising detailed fault traces and geologic data to constrain surface and sub-surface fault geometry) and the collection of field observations (to constrain long-term slip rates), slip rate variability over time appears as another key parameter that needs to be considered in future fault-based seismic hazard models, given that both coseismic and postseismic processes are possible explanations of the observation.

ROUND TABLE

Earthquake Supercycles and Earthquake Conversations, led by Lucilla Benedetti, Julián García-Mayordomo and Marco Pagani

The round table will first start with three mini-presentations illustrating these complex phenomena, highlighting its challenges and suggesting ways for modelling them in PSHA. That will be followed by questions raised from the audience which will definitely lead to an interesting and inspiring discussion. It follows the abstract of the three mini-presentations:

There have been a growing number of paleoseismological records suggesting strain released mainly through slip pulses associated with seismic clustering while strain accumulates assuming a constant loading rate with smaller or less frequent event or even quiescence time. Those so called supercycles have been observed worldwide on several types of faults. Moreover in some areas slip pulses appears actually synchronized over various fault systems suggesting slip could concentrate both in time but also in space switching from one area to another over a sequence of events. Lucilla Benedetti will present in 5 minutes a short review of those new observations showing few examples of datasets gathered worldwide.

Active fault databases are key for the application of seismic code provisions, particularly in the design of important infrastructures (eg. Eurocode-8). Traditionally, fault-seismic parameters provided in these databases are biased towards the application of the Characteristic Earthquake model, or even to exponential Gutenberg-Richter like models. Hence, a lot effort has been devoted to constraint uncertainties in fault-data involved in estimating maximum magnitude/moment (eg. fault geometry and dimension) and slip rate (age constraints and offset measurements) of predefined fault segments or sections. Julián García-Mayordomo will briefly show how the increasing body of observations relating to fault rupture as an interacting and complex system is challenging the practical uses of active fault databases in seismic code provisions.

The hazard component of the OpenQuake Engine contains a number of experimental, less-known features such as cluster models, mutually exclusive ruptures, non-parametric sources. They can be used for the implementation of more complex earthquake occurrence models. Marco Pagani will provide a short illustration of these features in the hope they will prompt a discussion on current needs and future challenges regarding the inclusion of fault complexity into the calculation of seismic hazard.

SESSION 1: The EBSZ (SE Spain) lab: advances in earthquake geology research and seismic hazard modelling

FT/PO 1.1 - Jorge Alonso-Henar jahenar@geo.ucm.es

ARCHITECTURE AND DETAILED KINEMATIC ANALYSIS OF THE FAULT ROCK OF THE ALHAMA DE MURCIA FAULT (SE IBERIA)

Jorge Alonso-Henar, Carlos Fernández, José Jesús Martínez-Díaz, Emilio Rodríguez-Escudero, Juan Miguel Insúa Arévalo, Carolina Canora Catalán, Paula Herrero-Barbero, José Luis Sánchez Roldán, José Antonio Álvarez-Gómez, Yolanda de Pro Díaz

This study is composed of both ongoing excavations and definitive results of analyses done with the aim of unravel the architecture of the shear zone and the complexities of its kinematics of different domains that compose the Alhama de Murcia Fault (AMF). We have resorted to the analytic model of general triclinic transpression with oblique extrusion. This study offers the possibility of testing the model with absolute data of active deformation such as GPS velocity gradients and opens a new methodological approach in the study of active fault zones, combining quantitative kinematics, microtectonics and geochemical analyses. The application of this model has been possible by means of an exhaustive exploration of the predictions of the model and their comparison with the orientation data of field kinematic markers (fault-slip data and reorientation of fold hinges during progressive deformation), GPS data and the kinematic study of the fault gouge. We constrained the values of the kinematic vorticity number, the orientation of the vorticity vector, the orientation of the local and regional convergence vectors, the angle of extrusion in the shear zone and the amount of extrusion. The obtained results point to a highly partitioned heterogeneous shear zone with domains showing competency contrasts: a low competency domain composed by the fault gouge, ductilely deformed, with low vorticity values, which probably experienced a steady-state, aseismic slip that reflects regional convergence vectors (convergence Eurasia–Nubia); and a domain out of the fault gouge that accommodates elastic energy, with higher vorticity values, and showing convergence vectors which are parallel to the local convergence vectors calculated from the GPS velocity field.

PO 1.2 – Belén Benito

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SEISMIC HAZARD SCENARIOS THROUGH DIFFERENT MODELING OF THE CARBONERAS FAULT AND ITS IMPACT ON THE EXPECTED GROUND MOTION IN THE CITY OF ALMERIA

Benito Oterino, MB; Rivas Medina, A., Gaspar-Escribano, J. and Staller, A.

The Carboneras Fault, located in the Southeast Iberian Peninsula, is one of those with the highest slip rate (α), among the active faults in Spain, and is also one of the longest (L), which also makes it one of the highest potential seismic, in terms of the scalar seismic moment that could be released (Mo). According to QAFI v3 (IGME, 2015), α = 1.1 mm / year and L = 110.5 km, which would make possible an earthquake of magnitude Mw = 7.4, (using the of W & C'94 empirical relationship) with a recurrence interval of TR = 1150 years. The fault is strike slip and paleoseismic studies point to a minimum of 6 events since the Mid Pleistocene observed in trenches along La Serrata (Moreno, 2010, Moreno et al., 2008) and an elapsed time for Mw 7.4 of 1178 years. On the other hand, the last major event reported historically in the fault is the one that occurred in 1522, with I (EMS) = IX and M = 6.5, which allows estimating an elapsed time of about 500 years for that magnitude. With the available data, hazard estimates have been developed from different fault modeling: 1) TC characteristic earthquake, 2) Brownian model of temporal dependence, 3) Renewal model and 4) Poisson model. The sensitivity of the results to the different source modeling is analyzed, and these are compared in turn with the PGA values of the latest seismic hazard map of Spain (UPM-IGN, 2013). Finally, we analyze the impact of the results in the city of Almeria, which is one of the most vulnerable cities in southern Spain. This way it is possible to propagate the sensitivity of source models into seismic risk results for the city, with the corresponding influence on the expected damage scenarios for future earthquakes.

FT 1.3 – Ferrán Estrada

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TSUNAMIGENIC RISK ASSOCIATED TO VERTICAL OFFSET IN TRANSCURRENT FAULT TERMINATION: THE CASE OF THE AVERROES FAULT (ALBORAN SEA)

Estrada, F., González-Vida, J.M., Peláez, J.A., Galindo-Zaldívar, J., Ercilla, G., Vázquez, J. T.

Traditionally, transcurrent faults in marine areas have not been considered as potential triggers of tsunamis due to their kinematics that do not displace the sea bottom. However, they may present significant vertical offsets at their terminations and therefore, be potentially tsunamigenic. With this scope, we analyze the active Averroes fault (AvF), a NW-SE dextral transcurrent structure with vertical offset at its northern termination. The AvF develops in an active context of tectonic indentation in the central Alboran Sea (Westernmost Mediterranean Sea), consequence of the Nubia-Eurasia plate's convergence. This fault is located in the southwestward prolongation of the Eastern Betic Shear Zone. The bathymetric and seismic analysis point to the AvF has a maximum vertical offset of 5.4 m for an earthquake of Mw =7.0. The crustal deformation at the sea bottom surface generated by this earthquake has been modeled using the Coulomb 3.3 code using the Okada's 1992 approach, assuming an elastic halfspace with uniform elastic properties. The deformation pattern is characterized by uplifting (footwall block) and subsiding (hanging wall block) lobes. The tsunami wave propagation generated by the seafloor deformation has been modeled with the Tsunami-HySEA (HySEA stands for Hyperbolic

Systems and Efficient Algorithms). The tsunami model shows the influence of the seafloor morphology in the wave propagation, the Spanish coast being the most affected margin by wave heights up to 2.5 m.

FT 1.4 – Jesús Galindo-Zaldívar jgalindo@ugr.es

THE AL HOCEIMA SEISMIC ZONE (SW PROLONGATION OF THE EBSZ IN THE RIF): GPS EVIDENCES OF DEEP TECTONIC DISPLACEMENTS ON A MAIN ACTIVE BLIND SINISTRAL FAULT

Jesus Galindo-Zaldívar, Antonio J. Gil, Omar Azzouz, Gemma Ercilla, Alberto Sánchez-Alzola, María C. de Lacy-Pérez de los Cobos, Antonio M. Ruiz-Armenteros, Said Bengamra, Ferran Estrada, Patricia Ruano and Mohamed Makkaoui

The Al Hoceima seismic zone is located at the southwestward prolongation of the Eastern Betic Shear Zone that crosses the Alboran Sea and reaches up to the Rif. This region was affected by the 1994, 2004 and 2016 onshore and offshore seismic crisis and constitutes one of the most active areas of the westernmost Mediterranean. The January 24, 2004 (M= 6.4, depth 7 to 10 km) earthquake was related to a NNE-SSW sinistral or a WNW-ESE dextral vertical fault, but in spite of its shallow origin, no tectonic field ruptures were recognized. Anyway, the epicentral region evidences NE-SW to E-W brittle extensional structures: Quaternary fractured pebbles, conjugate normal faults and open joints. The main normal and transtensional faults in the region are located eastwards of the zone affected by seismicity, onshore and offshore of the Nekor bay. A non-permanent GPS network composed by 6 sites and measured since June 2007 evidence very moderate or absent activity of the main outcropping faults surrounding the Nekor Basin. However, very high rates (up to 2- 3mm /yr) of ENE-WSW extension have been detected in the epicentral zone. These field data are in agreement with those obtained on the analysis of the 2016 seismic series in the Alboran Sea, that evidence a westward migration of the deformation in the region. While the main sinistral EBSZ propagates southwestward up to the Rif affecting the basement, shallow tectonics units probably are detached and only being affected by the extensional deformation above the deeper main crustal fault. This complex setting may constitute a key area to advance in paleoseismological and seismic hazard assessment studies because the main recent outcropping faults have become inactive and the new main active structures are blind strike-slip faults.

FT/PO 1.5 – Octavi Gómez Novell octgomez@ub.edu

FIRST PALEOSEISMIC EVIDENCE OF THE FRONTAL BRANCH OF ALHAMA DE MURCIA FAULT ZONE (EASTERN BETICS, SE SPAIN) AND ITS HOLOCENE ACTIVITY

Octavi Gómez-Novell, Maria Ortuño, Julián García-Mayordomo, Eulàlia Masana, Thomas Rockwell, Stéphane Baize, Robert López, Albert Baguer

The Alhama de Murcia fault system (AMF) is a left-lateral strike-slip structure within the Eastern Betics Shear Zone (EBSZ) which absorbs an important part of the shortening resulting from the convergence between the African and Nubian plates. In the Lorca-Totana section, the fault system is divided in three main branches: NW, central and SE or frontal. Most of the paleoseismic studies developed in this fault have focused on the central branch, because it is the one with most surface expression (e.g. geomorphological lineaments, deflected drainages, wind gaps, pressure ridges etc.). Conversely, no research to date has focused on characterizing the paleoseismic activity of the other branches in the section. In this study we present the first paleoseismic evidence of the frontal branch of AMF. We excavated 5 paleoseismic trenches in La Hoya site (Lorca, Spain) that exposed fault related deformation in at least two different generations of alluvial fan sediments. In the trenches dug in the oldest deposits, probably Late Pliocene-Early Quaternary in age, we observed strong deformation (tilting, folding and minor faulting), although no robust evidence of recent faulting was clearly recognized. Late Quaternary faulting was only observed in a trench dug within the deposits of el Colmenar creek, where it appears as a low angle reverse fault. Lower sedimentary units are offset up to 40 cm in the dip slip sense while upper units are offset only about 4 cm, proving recurrent activity of this fault branch during the Late Quaternary. A channelized unconsolidated gravel unit seals the fault at around 1 m from the actual surface of the creek. Radiocarbon dating was carried out in the most recent affected deposits, yielding ages from 8456 to 9743 cal BP. This demonstrates the occurrence of a young earthquake rupture posterior to these dates. No age data is currently available from the unaffected deposits (upper ~ 1 m of the stratigraphic sequence) and therefore, the upper bracket of this last event remains unconstrained. Further research will focus on constraining the Late Quaternary evolution of the deformation and the seismic events related to the frontal AMF branch in the studied site.

RT 1.6 – Eulalia Gràcia egracia@icm.csic.es

SEISMIC CRISIS REVEALS THE DEVELOPMENT OF AN INCIPIENT CONTINENTAL FAULT SYSTEM IN THE ALBORAN SEA

Eulàlia Gràcia, Ingo Grevemeyer, Rafael Bartolomé, Hector Perea, Sara Martínez-Loriente, Laura Gómez de la Peña, Antonio Villaseñor, Yann Klinger, Claudio Lo Iacono, Susana Diez, Alcinoe Calahorrano, Miquel Camafort, Sergio Costa, Elia d'Acremont, Alain Rabaute and César R. Ranero

Large continental faults extend for thousands of kilometres to form tectonic boundaries between plates, often associated with prominent topographic features. In these active areas, well-defined faults produce large earthquakes, and thus imply a high seismic hazard. These paradigms are called into question in the Alboran Sea, which hosts an allegedly complex diffuse boundary between the Eurasia and Nubia plates, and we discovered one of the few examples worldwide of the initial stages of these key tectonic structures. On the 25th January 2016, a magnitude Mw 6.4 submarine earthquake struck the north of the Moroccan coast, the largest event ever recorded in the Alboran Sea. The quake was preceded by an earthquake of magnitude Mw 5.1 and was followed by numerous aftershocks whose locations mainly migrated to the south. The mainshock nucleated at a releasing bend of the poorly known Al-Idrissi Fault System (AIFS). Here we combine newly acquired multi-scale bathymetric and seismic reflection data with a resolution, together with seismological data of the 2016 Mw 6.4 earthquake offshore Morocco – the largest event recorded in the area – to unveil the 3D geometry of the AIFS. We found that the AIFS is a crustal-scale boundary. We report evidence of left-lateral strike-slip displacement, characterize their fault segments and demonstrate that the AIFS is the source of the 2016 events. The occurrence of the Mw 6.4 earthquake and previous events of 1994 and 2004 supports that the AIFS is currently growing through propagation and linkage of its segments. The AIFS provides a unique model of the inception and growth of a young plate boundary. (Waiting for acceptance in NATURE COMMUNICATIONS, 2019).

FT/PO 1.7 – Paula Herrero-Barbero pherrerob@ucm.es

SLIP RATE DISTRIBUTION ALONG THE NORTHERN TERMINATION OF THE ALHAMA DE MURCIA FAULT

Paula Herrero-Barbero, José Antonio Álvarez-Gómez, José Jesús Martínez-Díaz

The NE sector of the Alhama de Murcia fault (Eastern Betic Shear Zone, SE Iberia) has been commonly considered as a fault section with hardly any Quaternary tectonic activity. The lack of geomorphological evidence showing a recent activity results in an absence of slip data estimated at the northern termination of the Alhama de Murcia fault. Approximately between Alhama de Murcia and Alcantarilla (~ 24 km), the Alhama de Murcia fault controlled the evolution of the Mula sedimentary sub-basin during Middle Miocene. The estimation of slip rates has been approached through the interpretation of seismic reflection profiles of the basin. Stratigraphic markers deformed by the fault have been used to restore the subsequent coseismic displacement owing to transpressive reactivation of the Alhama de Murcia fault in Upper Miocene. Through sequential restoration, a dip-slip rate of 0.16 – 0.26 mm/yr has been estimated (last 7.6 – 4.8 Ma), corresponding with a shortening rate of 0.08 – 0.13 mm/yr. 3D vertical displacement analysis along the fault trace also shows a decrease of throw from the Alhama de Murcia area towards the northeast, being negative at Alcantarilla. The slip rate seems to be higher than expected near Alhama de Murcia town (0.17 – 0.59 mm/yr) and is possibly lessened towards the NE by the transfer of deformation with nearby faults of the EBSZ (Carrascoy fault system, Bajo-Segura faults) in recent times. The historical seismic catalog contains references to EMS VI-VII earthquakes spatially associated with this Alhama de Murcia fault section, hence the net slip rates and seismic parameters derived from this research should be considered in hazard assessments, paying particular attention to the proximity of the Murcia city.

PO 1.8 – Juan M. Insua-Arévalo **insuarev@geo.ucm.es**

CHALLENGES FOR THE ESTIMATION OF THE SEISMIC POTENTIAL IN AREAS OF DISTRIBUTED DEFORMATION: THE CASE OF THE AREA BETWEEN THE PALOMARES AND CARRASCOY FAULTS (EASTERN BETIC SHEAR ZONE, SE IBERIA)

J.M. Insua-Arévalo, J. García-Mayordomo, J.L. Sánchez-Roldán, O. Gómez-Novell, S. Baize, H. Jomard , J.J. Martínez-Díaz, C. Canora-Catalán, P. Herrero-Barbero, R. López-Escudero, E. Masana

The Palomares and Carrascoy faults are two major faults of the Eastern Betic Shear Zone, both controlling conspicuous mountain fronts. However, the area in between both faults corresponds to a smooth plain bounded by a relief of smooth hills. Recent research and trenching studies has revealed that this relief is controlled by folds of variable amplitude nucleated in high angle reverse faults with sinistral component. This area defines a zone of distributed deformation of around 20x10 km in which the fault traces at the surface extend for distances from 1 to 6 km. The faults show an overlapping pattern and there is not a well-defined deformation front. Field research has showed that at outcrop scale (meters), the rupture becomes younger backwards on the hanging wall, conversely to the classical thrust propagation model. Additionally, available seismic profiles in the area show that some of these faults were normal faults related to a graben marine environment during the Upper Miocene. These faults were reactivated as reverse during Quaternary time within a tectonic inversion regional frame. All these characteristics challenge the definition of the seismogenic potential of the area itself and in relation to neighbouring Palomares and Carrascoy faults. We particularly question if this fault-distributed zone is capable of nucleate earthquakes of its own with isolated events relating to single ruptures each time, or, conversely, events generate several surface ruptures at the same time. We also question if ruptures in the area developed during major events in neighbouring Palomares and/or Carrascoy faults giving a complex rupture involving several regional faults at once. Current paleoseismological and morphotectonics research in the area will shed light in this issue and provide criteria for weighting different possible seismic hazard models for Palomares and Carrascoy faults.

FT 1.9 – Gia Khazaradze **gkhazar@ub.edu**

GEODETIC SLIP PARTITIONING BETWEEN THE ALHAMA DE MURCIA AND PALOMARES FAULTS IN THE SE BETICS, SPAIN

G. Khazaradze, A. Staller, R. López, J. J, Martínez-Diaz, E. Masana

It is generally assumed that most of the present-day deformation in the Eastern Betic Shear Zone (EBSZ) is assumed by the left-lateral strike-slip faults of Alhama de Murcia (AMF) and Carboneras (CF). Our previous geodetic investigations suggested fault perpendicular compression of 0.8±0.4 mm/yr and fault-parallel sinistral motion of 1.3±0.2 mm/yr for the AMF. However, these results didn't take into account a possibility of the relative partitioning of deformation between the AMF and Palomares (PF) faults, since no measurements were available at that time within the area separating the two faults. As a result, considering seismic and geologic arguments, the bulk of this geodetic slip was attributed to the AMF, ignoring the contribution of the PF. In June 2016, a new continuous GPS site SENM was established in Sierra Enmedio, located between the AMF and PF, in the Guadalentín depression. The preliminary results from the analysis of more than 2 years of continuous data from SENM indicate an intriguing and contradictory behavior of the PF: it shows that the PF is presently active and is accumulating a significant part of the strain, driven by the Nubia/Eurasia convergence, previously only attributed to the AMF. This new finding, if confirmed with longer and more reliable GPS time-series, might force us to reconsider established beliefs regarding the importance of the Palomares fault, with consequent implications for the seismic hazard evaluation in the region.

FT/PO 1.10 – Robert López Escudero **r.lopez.es@ub.edu**

REFINING SEISMIC PARAMETERS OF THE CARBONERAS FAULT (SE IBERIA) FROM LATE PLEISTOCENE TO EARLY HOLOCENE AT TOSTANA SITE

Robert López, Eulàlia Masana, Giorgi Khazaradze, Octavi Gomez-Novell, Raimon Pallàs, María Ortuño, Stéphane Baize, Thomas Rockwell

The Carboneras Fault (CF) is an active left-lateral strike-slip fault. It is the southernmost and longest (150 km) fault of the Eastern Betics Shear Zone (EBSZ) which absorbs part of the 4-5 mm/yr shortening between the Iberian and Nubian plates. La Serrata range, on the CF 50 km on-shore trace, forms a contractional duplex that bounds basement units and Quaternary alluvial fans to the northwest and Neogene vulcanism and alluvial fans to the southeast. New paleoseismological studies have been carried out on SE branch of La Serrata, more specifically in a late Pleistocene alluvial fan that overlaps the fault trace. In total, thirteen trenches were excavated, plus a series of twelve slices, on the apex of the alluvial fan. The trenches evidenced two big channel systems each of them filled up by an alternation of loose gravel channels, and wide layers of debris and mud flows. Although, up to 16 individual channels were identified throughout the trenches, only six were suitable for an offset calculation. The measured offset of the channels ranges from ~15 m on the older measured channel to ~4 m on the younger one. The trenches dug perpendicular to the fault, evidenced at least 4 to 5 paleoearthquakes, the last one reaching recent sediments. Altogether, 62 samples were dated: 43 radiocarbon samples (22 charcoals and 21 mollusk shells) and 19 aminoacid racemization on mollusk shells. 11 OSL samples are currently being dated. The age of the channels given by those datings span from ~45ka to ~0.5ka (cal BP) respectively, which allows to infer a slip rate of 0.2-0.5mm/yr. The young age of the last offset channel is consistent with the Alhama de Almería 1522 earthquake (EMS IX). Therefore, the offset of this last event could be understood as a slip per event of the fault and scaled to a Mw 7.0-7.2 earthquake with a rupture length of 46 to 58km. The analysis of all the site data is still on course and may be refined. As a side conclusion, this work could allow us to re-think that records of very young deformations can be found in a priori not optimal sites for this kind of research. The age of the channels, according to the numerical dating, span from ~45 ka to ~0.5 ka respectively, yielding a slip rate of 0.2-0.5 mm/yr. The youngest age of the last offset channel correlates well with the 1522 Alhama de Almería earthquake (EMS IX). This channel is offset by 3.8 m, probably corresponding to the same historical event and thus, can be used as a slip per event, a data not yet been defined along the Carboneras fault to date. This offset, that should be understood as a maximum slip per event, scales with a Mw 7.0±0.1 earthquake with a fault rupture length of 46 to 58 km, in a similar way to what can be estimated if the complete Carboneras fault ruptures during an earthquake. The analysis of all the site data is still ongoing and the results presented here can be further refined.

RT 1.11 – Iván Martín-Rojas **ivan.martin@ua.es**

FORWARDS AND BACKWARDS BETWEEN FIELD DATA AND SEISMIC HAZARD ANALYSIS: THE BAZA FAULT

Iván Martín-Rojas, José Antonio Peláez, Iván Medina-Cascales, Francisco Juan García-Tortosa, Pedro Alfaro

The Baza Fault (BF) is one of the more active structures in the central Betic Cordillera (Spain). This normal fault ruptured in 1531 AD in a macroseismic ~ M=6 event responsible for almost 400 casualties. Available palaeoseismic field data are compatible with different palaeoseismic histories, involving a variable number of events. Some of these different hypotheses are related to the surface rupture of the 1531 AD event. We carry out a geodetic analysis for the 1531 AD event. In this analysis we consider two scenarios. A first scenario rupturing the complete BF and a second one involving a partial rupture (north section). In the first scenario, deformation is quite similar all along the fault trace. In the second scenario, only the north section undergoes significant deformation. This second scenario agrees with damages reported in historical descriptions. Consequently, we postulate that the 1531 AD event was probably produced by a partial rupture of the north section of the Baza Fault. We also study the palaeoseismic history of the Baza Fault in order to fit these data to different temporal distributions. We consider two hypotheses, corresponding to palaeoseismic histories which involve 8 and 9 palaeoseismic events, respectively. The hypothesis involving 8 events yields a significantly lower uncertainty than the 9 events hypothesis. This could be interpreted as an evidence supporting that the palaeoseismic histories involving a minimum number of events are more likely.

PO 1.12 – Sara Martínez-Loriente smartinez@icm.csic.es

ACTIVE TECTONICS, CRUSTAL STRUCTURE AND AFFINITY OF THE BASEMENT DOMAINS OFFSHORE SW IBERIA. REGIONAL GEODYNAMIC IMPLICATIONS OF THE AFRICA-EURASIA PLATE BOUNDARY

Sara Martínez-Loriente, Valentí Sallarès, Eulàlia Gràcia

We present a new classification of geological domains at the Africa-Eurasia plate boundary off SW Iberia, together with a regional geodynamic reconstruction spanning from the Mesozoic extension to the Neogene-to-present-day convergence. It is based on seismic velocity and density models along two regional wide-angle seismic transects, combined with previously available information. The seismic velocity and density structure at the Seine Abyssal Plain (SAP) and the internal Gulf of Cadiz (GC) indicates the presence of a highly heterogeneous oceanic crust, whereas in the Horseshoe and Tagus abyssal plains, the basement structure resembles that of exhumed mantle sections identified in the Northern Atlantic margin. The integration of all this new information allows defining the presence of 3 oceanic domains off SW Iberia: (1) the SAP domain, generated during the first stages of slow seafloor spreading in the NE Central Atlantic (Early Jurassic); (2) the GC domain, made of oceanic crust generated in the Alpine-Tethys spreading system between Iberia and Africa, which was coeval with the formation of the SAP domain and lasted up to the North Atlantic continental break-up (Late Jurassic); and (3) the Gorringe Bank (GB) domain, mainly made of rocks exhumed from the mantle with little synchronous magmatism, which formed during the first stages of North Atlantic opening. Our models suggest that the SAP and GC domains are separated by the Lineament South strike-slip fault, whereas the GC and GB domains appear to be limited by a deep thrust fault located at the center of the Horseshoe Abyssal Plain. The formation and evolution of these 3 domains during the Mesozoic is key to understand the sequence of events that occurred during the first stages of opening of the Northern Atlantic.

FT/PO 1.13 – Iván Medina-Cascales ivan.medina@ua.es

SEISMOGENIC SOURCE OF THE 1919 TORREMENDO EARTHQUAKE

Ivan Medina-Cascales, Pedro Alfaro and Iván Martín-Rojas

The 10th September 1919 Torremendo (Jacarilla) earthquake is one of the most significant events occurred in the eastern Betic Cordillera during the instrumental period. It consists of two main shocks with an estimated magnitude varying between M= 4.8 to 5.5, according to different authors. These earthquakes caused moderate damages in several towns in the Bajo Segura region (Alicante province, SE Spain). Intensity maps show two main zones with high values: in Torremendo town (VII-VIII) and in some towns located in the Segura valley (VII). Epicentral location is controversial. Several studies locate the epicenter very close to the surface trace of the Bajo Segura Fault (BSF). The BSF is an E-W reverse blind fault, dipping 30-45° to the South. Considering its geometry and the maximum intensity (VII-VIII) in Torremendo town, located ~ 8 km south of the Bajo Segura fault trace, we agree with studies which locate the epicenter around Torremendo. The second high intensity zone, located in the Segura valley, is related with the site effect produced by poorly consolidated Holocene deposits of the Segura River. In the region, the Bajo Segura Fault is divided in two main splays: the Bajo Segura s.s. and Torremendo faults. If we consider dips between 30 and 45°, and a minimum depth for a M ~5 earthquake, the most probable seismogenic source may be the Bajo Segura s.s. splay.

FT/PO 1.14 - Luca Moratto lmoratto@inogs.it

THE 2011 MW 5.2 LORCA EARTHQUAKE AS A CASE STUDY TO INVESTIGATE THE GROUND MOTION VARIABILITY RELATED TO THE SOURCE MODEL

Angela Saraò, Alessandro Vuan, Marco Mucciarelli, Maria José Jiménez, Mariano Garcıa-Fernandez

Near-field recordings are very sensitive to the spatiotemporal details of the rupture process while far-field signals show the signature of the overall ‘‘point-source’’ earthquake mechanism. Near- and far-field recording ranges are dependent on the event magnitude and modulate the variability of the ground motion. This study investigates the ground motion and

the source-related near-field variability for the 2011 Lorca earthquake, a moderate seismic event (Mw = 5.2) that caused significant localized damage in the Region of Murcia, Spain. The low-frequency content (up to 1 Hz) is simulated by the wavenumber integration method assuming four different source models obtained by inversion of geodetic or seismological data. As a first result, we estimate the variability of the ground motion. We observe that the dispersion in the peak and spectral parameters is larger at LOR, the closest station to the source, and decreases as the source distance increases (more than 50 km far from the source) where the finite-fault effects become negligible. The variability of the pseudo spectral velocity at 2 s is within the ground motion prediction equation ±1 sigma, apart from the very near-source station and those stations affected by forward directivity effects. These effects are also found in high-frequency seismograms obtained by the empirical Green's functions approach.

PO 1.15 – Alicia Rivas **alicia.rivas@upm.es**

IMPACT OF THE FAULTS MODELING IN PROBABILISTIC SEISMIC HAZARD ASSESSMENT (PSHA) IN SOUTH AND SOUTHEASTERN CITIES OF SPAIN

Rivas Medina, A; Benito Oterino, MB; Gaspar-Escribano, J.

It is known that the introduction of faults as independent seismic sources in hazard assessment has a great impact on the results, with respect to those obtained with classical zoning methods (CZM). Although at the moment there are no widely contrasted methodological developments to combine zones and faults in the source models, some approaches that have used hybrid models (HM), such as that proposed by Rivas-Medina et al. (2019), reveal that expected ground motion values around main faults may double (on average) those obtained by zoned models, in agreement with observations in recent earthquakes. This fact has a great impact on the hazard and seismic risk results that can be obtained in populations close to active faults. In this paper, we analyze the influence of fault modeling as independent sources in three cities in the south and southeast of Spain, specifically in Malaga, Granada and Murcia. First, we compare the hazard results obtained (curves and response spectra) in the three cities by both methods, CZM and HM. Then, the faults that contribute most to the hazard for different return and structural periods are identified and the controlling earthquakes or dominant seismic scenarios are established by disaggregation procedure. Finally, the expected ground motion parameters due to these seismic scenarios are estimated. The main results for the return period of 475 years are that the dominant faults turn out to be Mijas (in Málaga), Fargue-Jun (in Granada) and Alhama de Murcia, Bajo Segura and Carrascoy (in Murcia). The controlling earthquakes in general correspond to the ranges of magnitude Mw (5.5 - 6.0), in the three cities, and distances Rrup (15-20 km) in Malaga and from (5-10 km) in Granada and Murcia, which implies expected accelerations of the order of 0.13 g in the first city and 0.35 g in the last two, considering in all cases generic rock sites.

PO 1.16 – Emilio Rodríguez-Escudero **emilio.rodriguez@uam.es**

SEISMIC HAZARD IMPLICATIONS OF THE INTERNAL STRUCTURE OF THE ALHAMA DE MURCIA FAULT (SE SPAIN)

Emilio Rodríguez-Escudero, José J. Martínez-Díaz, André R. Niemeijer, Meaza Tsige, Jorge L. Giner-Robles, Jorge Alonso-Henar, J. Miguel Insua-Arévalo, J.A. Álvarez-Gómez

Elucidating the internal structure of the Alhama de Murcia Fault (AMF) in SE Spain is essential to proper understanding its seismological behavior. To this end, a structural analysis from detailed mapping, trenches and a 174 m deep borehole, was performed in the Goñar-Lorca section of the AMF, where the fault zone is better exposed and the deformation is concentrated in a unique branch. Results from this analysis provide evidence of a highly asymmetric >100 m wide fault zone. A ~20 m thick layer of phyllosilicate-rich black gouges always outcrops adjacent, with a very sharp contact, to graphitic schists from the metamorphic basement which constitute the hanging wall. Mineralogical and microstructural analyses indicate that gouges derived by mechanical alteration from graphitic schist, suggesting that they may be representative of the fault core rocks accommodating deformation at depth. The gouges display distributed deformation and demonstrate velocity hardening during frictional experiments. The gouges also include quartz clasts that are deduced to have been pulverized by coseismic strain. The AMF is inferred to have a mixed mode seismicity, with fault creep within the black gouge punctuated by seismic ruptures. While the frictional properties of the gouge could inhibit the earthquake rupture propagation along the AMF, creep may favors a progressive concentration of weak minerals (e.g. graphite) along potential slip surfaces within the gouge layer that could involve larger ruptures. In addition, a higher permeability parallel to the gouge foliation from depth may play an important role in hydro-mechanical processes, such as fluid overpressure during seismic events and new mineralization healing the fault zone and/or reversing the frictional properties of the gouges.

PO 1.17 – Víctor Tendero-Salmerón vtendero@ugr.es

EASTERN GUADALQUIVIR BASIN SEISMICITY RELATED TO STRIKE-SLIP FAULTING: GEODYNAMICS IMPLICATIONS IN THE EASTERN BETIC CORDILLERA

Víctor Tendero-Salmerón, Jesús Galindo-Zaldívar, José A. Peláez, Manuel Martínez-Martos, Jesús Henares, Carlos Marín-Lechado, Antonio J. Gil, Ángel Carlos López-Garrido

Eastern Guadalquivir foreland basin has been affected by unexpected seismicity with earthquakes reaching up to mbLg 4.1 in the recent seismic series of Peal del Becerro, westward of Cazorla Range (Betic Cordillera, SE Spain). These earthquakes are caused by strike-slip faulting located in the basement (from 1 to 15 km deep). New geophysical and geological data combined with seismological information, such as relocated hypocentres, evidence the very recent tectonic activity in this area. Thus, our results show two main seismic clusters at different depths associated to a NNE-SSW almost pure sinistral fault that extends 16 km in length. The soft sedimentary infill is slightly deformed by recent tectonic structures including scarce faulting evidences. Therefore, we propose a sinistral fault as the cause of the seismicity. This fault is nucleated in the basement and it is propagating upwards and southwards, according to hypocentres distribution. This fault is of the same set than the roughly parallel sinistral Palomares fault in the EBSZ, located at the westward boundary of the Aguilas Arc, suggesting a common origin. However, the Peal del Becerro fault may be in an initial stage developed mainly in the basement rocks. Thus, future researches in the region may consider the propagation of the faults of the EBSZ tectonic pattern to other parts of the Betic Cordillera.

FT 1.18 – Juan Tomás Vázquez juantomas.vazquez@ieo.es

NNE-SSW LEFT-LATERAL ACTIVE FAULTS IN THE MOTRIL-DJIBOUTI MARGINAL PLATEAU, NORTHERN MARGIN OF THE ALBORAN SEA (WESTERN MEDITERRANEAN)

J.T. Vázquez, F. Estrada, E. Ercilla, E. D’Acremont, J. Galindo-Zaldívar, D. Palomino, B. Alonso, C. Juan, Ch. Gorini and R. Vegas

Seafloor of the Alboran Sea is characterized by a penetrative system of tectonic structures that are well defined both by displacement and folding of Quaternary sedimentary units and formation of several marked morphological features related to contemporary faulting activity. These structures are evidenced in multibeam bathymetry mosaics and subsurface parametric and high resolution seismic (airgun, sparker) profiles, which allow to analyze their strong deformation. The pattern of seismic epicentres distribution has also a good correlation with these structures. The group of Quaternary structures is constituted by three families of strike-slip faults that they work as a conjugated system. The first one has a WNW-ESE to NW-SE trend and right-lateral shear movement, and the other two have respectively NE-SW and NNE-SSW geometry and a left-lateral shear displacement. The activity of NNE-SSW family is recent than the NE-SW one since they displace them. Likewise it has been recognized the presence of N-S trending normal faults and NE-SW anticline folds. The Motril-Djibouti marginal plateau (northern margin of Alboran Sea) on the southwestward prolongation of the Eastern Betic Shear Zone, is crossed by at least eight active fault zones of NNE-SSW direction. They are characterized on the seafloor by corridors of fault escarpments and tectonic depressions, both grabens and halfgrabens, as minor pull-apart basins. The corridors length vary between 18 and 48 km and their widths between 0.2 and 3.9 km. A dense secondary N-S normal faulting is related to the strike-slip movement of the main faults. The main fault zones currently are responsible of a large part of the regional seismicity. The eastern fault zone corresponds to the northern prolongation of the Al Idrissi fault.

SESSION 2: Earthquake fault rupture and slip complexities: How-To OBSERVE them from field data

RT 2.1 - Solène Antoine **santoine@ipgp.fr**

NEAR-FAULT VARIATIONS OF SLIP AND STRAIN FOR A COMPLEX RUPTURE ZONE OF THE BALUCHISTAN EARTHQUAKE (PAKISTAN, 2013)

Solène Antoine, Yann Klinger, Arthur Delorme, Ryan Gold, Elwina Rupnick and Marc Pierrot-Deseilligny

Imaging the near-fault deformation field for large earthquakes has long been a challenging task while it became a critical information for Fault Displacement Hazard Assessment. Classical methods as InSAR and field studies have a hard time grasping the complexity of deformation near the fault zone. Correlation methods using high-resolution optical images appear to be the solution to characterize the displacement field near the fault zone. In this work, we use very high-resolution (0.5 meters ground resolution) images and a sub-pixel correlator (MicMac, IPGP-IGN) to measure the near-fault displacement field associated with the 2013 Baluchistan rupture (Mw 7.7, Pakistan). We focus on two different geometric complexities and show how deformation distributes within the first kilometers around the fault zone. Our results show significant variations in slip distribution, ranging from a very localized fault zone to a largely distributed (up to 1 kilometer) rupture area. Organization of the activated fault strands in the two relay zones show that geological fabric in the mountain range has a main role in controlling the fault surface rupture. Time evolution of these complexities is inferred from both structural and displacement analysis. Also, distributed volumetric deformation is measured and appears to occur only in the hanging wall, associated with the two relay zones. In these areas, many faults strands are activated to accommodate the co-seismic slip. Analysis of divergence and curl components of strain show that volumetric deformation can either be distributed extension or rotation or both. Future studies aim at extending this work to the entire Baluchistan rupture and at characterizing horizontal post-seismic deformation using series of images taken after the earthquake.

PO 2.2 – Raffaele Azzaro **raffaele.azzaro@ingv.it**

THE 2018 MW4.9 ETNA EARTHQUAKE: HOW FAULT RUPTURE FITS SHA BASED ON GEOLOGIC APPROACHES

R. Azzaro and the EMERGEO Working Group (Emergenza Etna 2018)

At Mt Etna (Italy) volcano-tectonic earthquakes produce impressive surface faulting despite their moderate magnitude (Mmax ~ 5.0), with historically documented ruptures featuring end-to-end lengths of 6-7 km. This kind of data is also considered for local SHA studies and allow to better constrain the seismic source. Here we present field data collected following the 26 December 2018, Mw4.9 earthquake, which represents the strongest event occurred at Etna in the last 70 years. The EMERGEO Working Group of the Istituto Nazionale di Geofisica e Vulcanologia promptly activated to map the coseismic ruptures along the Fiandaca fault (FF), a hidden structure in the volcano's eastern flank. The survey has produced ca. 1000 points of measurements relative to geometry, kinematics and offset of the ruptures; overall surface faulting extended for 7.5 km, being characterised by dextral, oblique-slip displacements up to 35 cm. The main deformation zone, tens of meter wide, is composed by sub-parallel ruptures in a left-stepping arrangement and develops along the long-term geomorphic evidence of the fault. Evidence of multi-fault ruptures, or triggered faulting, is observed along a splay fault branching out from FF. Data collected are finally compared with the results of SHA recently performed at Etna, that uses tectonic data (code FiSH) to quantify the maximum expected magnitude and the mean recurrence time of the expected earthquakes.

PO 2.3 – Stéphane Baize **stephane.baize@irsn.fr**

A WORLDWIDE AND UNIFIED DATABASE OF SURFACE RUPTURES (SURE) FOR FAULT DISPLACEMENT HAZARD ANALYSES

Baize, S., Nurminen, F., Sarmiento, A., Dawson, T., Takao, M., Scotti, O., Azuma, T., Boncio, P., Champenois, J., Cinti, F. R., Civico, R., Costa, C., Guerrieri, L., Marti, E., McCalpin, J., Okumura, K., Villamor, P.

FDHA is based on empirical relationships established using historic earthquake fault ruptures. These relationships evaluate the likelihood of coseismic surface slip considering on-fault and off-fault ruptures, for given earthquake magnitude and distance to fault. Moreover, they allow predicting the amount of fault slip at and close to the active fault of concern. Applications of this approach include land use planning, structural design of infrastructure and critical facilities located close to an active fault. To date, the current equations are based on sparsely populated datasets, including a limited number of pre-2000 events. In 2015, an international effort started to constitute a worldwide and unified surface co-seismic displacements database (SURE) to improve further fault displacements estimations. Two workshops have been held, and it was decided to (1) unify the existing datasets; (2) to include recent cases which deformation have been captured with modern techniques; (3) to account for parameters relevant to properly describe the rupture (e.g. surface geology). The SURE database is published with a companion paper. It encompasses 44 earthquakes from magnitude 5 to 7.9, with ~10 thousands slip measurements and more than 50 thousands of rupture segments. The database contains 44 earthquakes (23 strike-slip, 11 normal, 10 reverse) in the magnitude range 5 to 7.9, with more than 10,000 slip measurements and 50,000 rupture segments. To date, 20 cases are from Japan and 14 from the western USA.The initial and common effort needs to be continued and coordinated; and the maintenance and life of the database must be guaranteed. This effort will remain based on a large and open community of earthquake geologists to create a free and open access database.

FT 2.4 – Paolo Boncio **paolo.boncio@unich.it**

IMPROVING THE KNOWLEDGE OF FAULTS 4 SOUTHERN APENNINES SHA: THE SOUTHERN MATESE NORMAL FAULTS (ITALY)

Paolo Boncio, Eugenio Auciello, Vincenzo Amato, Pietro Aucelli

The Sannio-Matese area, at the junction between the central and southern Apennines, was struck by at least 5 destructive earthquakes during the last 1700 years. GPS data show high extension rates across the area (2-3 mm/yr). Only two faults were associated to strong historical earthquakes, one in north-eastern Matese and one in western Matese. These faults are not sufficient to justify the observed geodetic deformation. A more complete model of active faults and fault segmentation seems to be necessary to account for the active strain field and seismicity. Geologic field work in southern Matese indicates that at least one seismogenic source should be added to the presently-known scenario: the Ailano – Piedimonte Matese – Gioia Sannitica fault (APGF) in southern Matese. This fault is organized in two NW-SE-striking sections, SW-dipping, and a central nearly E-W-striking section. This complex geometry is due to interplay between newly-formed faults and reactivation of old discontinuities. Here we present geologic evidence of Late Quaternary faulting along the APGF. The fault displaces post-Late Glacial Maximum morphologies, fan gravels with tephra interlayers erupted by the Roccamonfina volcano with Ar/Ar ages ranging from 560 to 190 ka, and colluvial/soil deposits of Holocene radiocarbon age. The resulting long-term throw rate is on the order of 0.15-0.3 mm/yr. The geology of the APGF and its relationship with the surrounding faults suggest that the fault is the plausible source of poorly-known historical destructive earthquakes, such as the 346/355 AD and 1293 Matese earthquakes. The results can improve SH estimates based on geologically-constrained seismic faults. Complex rupture patterns can be envisaged based on the observed long-term geologic fault pattern.

PO 2.5 – Youcef Bouhadad **bouhadad_y@yahoo.com**

ACTIVE TECTONICS RELATED -GEOMORPHIC AND GEOLOGICAL FEATURES IN THE LOWER CHELLIF BASIN (TELL ATLAS, ALGERIA)

Y. Bouhadad

Field geological data remain a problematic aspect in seismic hazard analysis. They constitute the main source of epistemic/scientific uncertainties that affect the reliability of seismic hazard models. The compressional active tectonics zones, where active faults may be partly or entirely blind and emergent, exhibit often a complex deformation which makes observations on slip rate, fault geometry and fault segmentation difficult. The western Chellif (Tell Atlas chain) area shows impressive active tectonics- related geomorphic and geological features such as drainage network diversion, uplift of alluvial terraces, coastal notches, as well as main and secondary fault scarps. Furthermore, sedimentary features such as seismites and paleoliquefaction are abundant in Quaternary deposits. We aim in this work to discuss ways that allow to translate such features in terms of input data for seismic hazard analysis and how to overcome problems related to seismites dating and uncertainties related to quantification of geomorphic features.

PO 2.6 – Oualid Boulahia **o.boulahia@craag.dz**

SOURCE PARAMETERS AND COULOMB STRESS ANALYSIS FOR INTERACTED ADJACENT FAULT SEGMENTS IN NORTHEASTERN ALGERIA

Oualid Boulahia, Abdelkarim Yelles-Chaouche, Issam Abacha, Hamoud Beldjoudi

Moderate to low magnitude characterizes the seismicity of Northeast Algeria. In 2010 Beni-Ilmane (north-central Algeria) has experienced unseen seismic sequence with three successive main shocks of magnitude ($5 \leq Mw \leq 5.2$) on two adjacent fault segments, one left lateral fault oriented NNE-SSW and the other an E-W reverse fault. In May 2013 two main shocks of magnitude (Mw=5.2 and 5.0) occurred in Bejaia offshore (Northeastern Algeria) region six months after the one of November 2012 (Mw=5.1) on four segments belonging to right-lateral strike-slip fault trending NW-SE. Source parameters were estimated for the 18 largest events ($Md \geq 4$) of the 2010 Beni-Ilmane earthquake sequence and the 29 largest events ($Md \geq 3$) of Bejaia sequence using data recorded by permanent broadband seismic stations of the Algeria Digital Seismic Network (ADSN). Displacement spectra of P and S waves were estimated using a Brune seismic source model to compute spectral parameters. Spectra were corrected to account for path effects and near-surface attenuation. Modeling of the coseismic Coulomb static stress changes generated by the two sequences was performed in order to find a possible stress transfer between the several active segments. Interacting systems, source parameters and scaling laws to calculate empirical GMPEs is of foremost importance because the assessment of earthquake hazard to engineered structures requires ground motion relations that accurately characterize peak ground motions and response spectra as functions of earthquake magnitude and distance. Observing the complexity in the fault system of the two regions through the analyses performed, we like to deepen the study of complex fault interactions through rupture modeling.

RT 2.7 – Joanna Faure-Walker **j.faure-walker@ucl.ac.uk**

CHANGES IN CO-SEISMIC THROW AND SLIP AT FAULT BENDS AND FAULT SCALING RELATIONSHIPS

Francesco Iezzi, Zoë Mildon, Joanna Faure Walker, Gerald Roberts, Huw Goodall, Maxwell Wilkinson, and Jennifer Robertson

Fault scaling relationships that relate fault length with maximum displacement and maximum earthquake magnitude are often used to inform seismic hazard analyses. However, the data inputs into these relationships display a broad scatter. We use field measurements of coseismic surface slip during the August and October 2016 central Italy earthquakes to propose a reason for this scatter. Measurements of co-seismic slip of the August and October 2016 central Italy earthquakes reveal that there was greater slip across where there was a bend in the fault strike. Such a relationship has been identified in further normal faulting earthquakes worldwide. These results are consistent with models of long-term throw-rates and slip-rates showing a similar pattern of higher rates across fault bends, explained through strain-rate conservation along the length of the fault in the "geometry-dependent throw-rate model". Since scaling relationships relating fault length of coseismic maximum displacement were not developed with consideration of fault bends, the inputs may have events with measurements taken either at sites with higher displacements measured across fault bends or at sites away from fault bends and thus with smaller displacements. Therefore, when interpreting scaling relationships it is important to be aware whether there are bends across the faults affecting the maximum displacement. Fault bends and changes in co-seismic displacement across them should be taken into consideration when using scaling relationships to infer parameters for seismic hazard calculations.

RT 2.8 – Francesca Ferrario francesca.ferrario@uninsubria.it

MOVING TOWARD THE OBSERVATION OF A FULL SPECTRUM OF FAULT RUPTURE MODES: A DREADFUL SPECTRE FOR MODELERS?

Ferrario M.F., Livio F., Michetti A.M.

Recent strong earthquakes were claimed as the most complex ever recorded, in terms of spatial and temporal evolution of the sequence (e.g., 2016-2017 Central Italy), number of ruptured faults (2016 Kaikoura, New Zealand) and distribution of earthquake-triggered effects (landslides: 2018 Hokkaido, Japan; tsunami: 2018 Palu, Indonesia). Our understanding of the seismic cycle is fast evolving because earthquake dynamics and effects are nowadays captured with unprecedented detail. Datasets derived from surface, subsurface and remote-sensed observations show a full spectrum of possible occurrences between end-members, including: i) brittle ruptures on discrete surface breaks vs broad off-fault deformation; ii) displacement on the primary fault vs distributed faulting; iii) slip effectively transferred from depth to the surface vs blind ruptures, including uncertainty about the role played by gravity deformation. Some of these features cannot be recognized for past events (e.g., broad deformation, cluster of events below the resolution limit of dating techniques), thus modern case histories are needed to tailor the outcome of paleoseismological investigations. Accounting for the complexity of fault rupture modes into seismic hazard practice is a challenge but also gives the opportunity to foster the birth of a new generation of modeling techniques.

FT 2.9 – Yann Klinger klinger@ipgp.fr

SLOW SLIP RATE AND LONG RETURN PERIOD OF LARGE EARTHQUAKES IN THE TRACE OF THE 1967 M7 MOGOD EARTHQUAKE (MONGOLIA)

Y. Klinger, L. Bollinger, S. Forman, O. Chimed, A. Bayasgalan, U. Munkhuu and G. Davaasuren

Mongolia was affected in the 20th century by four major strike-slip earthquakes (M8) which spectacular surface ruptures are still fresh in the landscape. These structures were preexisting those earthquakes and have a prior long standing polyphased tectonic history. In addition to these major earthquakes, a large event, the M7 1967 Mogod earthquake, happened off- what was considered the major tectonic structures at the margin of a tectonic setting usually considered as a stable continental region. This earthquake ruptured a 40 km-long stretch of faults between the Hangay dome and eastern Mongolia. The rupture is divided in 3 main fault strands, which show either evidence of left-lateral strike-slip or thrust motion. Despite the spectacular surface ruptures associated to the 1967 event, in most places no cumulated seismic scarp could be found, raising questions about the past history of this active fault, its seismogenic potential and the seismic hazard associated to it. We documented a paleoseismological trench through one of the 1967 rupture section to unravel the past history of this active fault system. The excavation through the local reverse fault scarplet revealed at least 3 earthquakes that deformed and offset the superficial units by recumbent folding, drag folding and backthrusting. The chronology of the sequence is constrained by 7 OSL dates of sands sampled within the main units. The last surface rupture in 1967 CE was preceded by a similar event that happened between 20 and 40 ky and a third one around 50 ky. This result suggests that this slow slipping intraplate fault has a seismic cycle generating M7 events with an inter- event time of about 25 ka, an activity rate consistent with a slip on the fault around 0.1 mm/yr.

FT/PO 2.10 – Francesco Maesano **francesco.maesano@ingv.it**

NEW OBSERVED EVIDENCE OF ACTIVE FAULTING IN AN OFFSHORE FORELAND REGION: THE SOUTH APULIA FAULT SYSTEM

Maesano F.E., Volpi V., Civile D., Conti A., Accettella D., Tiberti M.M., Conte R., Zgur F., Basili R., Rossi G.

In this contribution we present the interpretation of a dense network of multichannel seismic profiles (part of which are provided by Spectrum Geo), multibeam high-resolution bathymetry, and CHIRP profiles recently acquired by R/V OGS Explora in the Northern Ionian Sea (Italy, Greece) where we found evidence of a 100 km long active fault system within the Adria microplate, which is the common foreland of the Albanides-Hellenides and Apennines chains. The analysis of our multiscale dataset allowed us to identify and correlate laterally a major NW-SE fault system, here named South Apulia Fault System (SAFS), whose activity started in the Plio-Pleistocene. The morpho-bathymetric and the subsurface geophysical data suggest that the SAFS activity carries on today. This achievement represents a step forward in the assessment of seismic and tsunami hazard in this cross-border region, located in a presumably stable region disconnected from the major nearby plate boundary. In this region the instrumental seismicity shows only few and scattered small earthquakes and the geodetic data reveal very slow strain rates, nonetheless the historical catalogues recall us about an Mw 6.7 earthquake occurred in the 1743 that spread damage in southern Italy, Albania, and Greece, together with hints about a tsunami in the Brindisi harbor. The source of this earthquake is very uncertain and raises compelling questions on how to treat this type of seismic sources in hazard maps.

FT 2.11 – Fidel Martín-González **fidel.martin@urjc.es**

COMPLEXITY IN INTRAPLATE ACTIVE FAULT GEOMETRIES: IMPLICATIONS FOR SEISMIC HAZARD

F. Martín-González and N. Heredia

A good knowledge of the geometry of the segments that can be involved in a rupture during an earthquake is needed to evaluate the fault parameters required for a fault-based seismic hazard assessment. In active intraplate faults, the long recurrences and long interseismic periods make difficult to define the segments and geometries due to the low seismic activity and degradation of the geological and geomorphological record, which prevents detailed seismological and paleoseismic studies. Moreover, in intraplate regions, the active faults are the results of inversion and reactivation of previous structures which makes geometries much more complex. This is due to the reactivation of certain segments or planes of these previous structures, in many cases with different kinematics. For these reasons, in some cases, these active faults are included in the active faults catalogs as barely segmented long faults or with the geometries and kinematics of the previous structures. In this work we study the geometries of two intraplate faults in the Cantabrian Mountains and the uncertainties in the segmentations of this kind of faults. It is observed that the fault plane is not a single plane geometry but the result of multiple fault planes reactivated, and that despite the large length of the structures (450 km), the different geometries and intersections with previous structures makes it very difficult to complete rupture of the whole fault during a single event without the rupture of multiple segments and faults.

FT 2.12 – Iván Martín-Rojas **ivan.martin@ua.es**

EVIDENCING COMPLEX FAULT RUPTURES BY BAYESIAN STATISTICAL ANALYSIS OF PALAEO-EARTHQUAKES. COULD THE 2016 KAIKŌURA EARTHQUAKE HAVE PROPAGATED FURTHER NORTH?

Iván Martin-Rojas, Juan Miguel Insua-Arévalo, Pilar Villamor, Fidel Martín González, José Jesús Martínez-Díaz, Robert M. Langridge, Russ J.Van Dissen

Several seismic events in the last years have shown how ruptures can propagate along multiple fractures previously considered as individual faults. The last of these complex ruptures was the November 2016 Mw 7.8 Kaikōura earthquake.

This earthquake ruptured ∼20 faults within an ∼180-km-long, northeast–southwest (NE–SW)-trending swath in NE South Island, New Zealand. We propose here an application of the Bayesian Statistical Analysis to unravel complex palaeo-earthquakes ruptures. For this purpose, we revisit all the available palaeoseismic data of the Kekerengu-Needles Fault System. This structure represents the northern end of the fault system involved in the 2016 Kaikōura earthquake. We also study its structural prolongation to the north, the Wairarapa Fault. We constructed Oxcal models for each site, to obtain probability density functions (PDF) for each postulated palaeoearthquake. Then, we reconstruct the composite surface rupture histories of each fault system analyzing the degree of overlap between the PDFs of the postulated palaeo-events. After that, we repeat this overlap analysis at a fault-scale, comparing the events proposed for the composite surface ruptures of each fault, in order to identify possible complex palaeo-ruptures. After all this analysis we postulate that two complex ruptures involving both the Kekerengu-Needles Faults System and the Wairarapa could have occurred in the last ca. 2000 years. Our results do not discriminate if these complex ruptures were actually single events or two different palaeoearthquakes occurred close in time. In any case, our analysis further support a possible stress triggering between the Kekerengu-Needles Fault System and the Wairarapa faults, pointing to a potential complex rupture involving both structures.

FT/PO 2.13 – Alba Peiro **apeiro@unizar.es**

FAULT RELAY ZONES WITHIN THE TERUEL GRABEN SYSTEM (EASTERN IBERIAN CHAIN): GEOMETRIES, INTERACTIONS AND SEISMOLOGICAL IMPLICATIONS

Alba Peiro, José Luis Simón y Teresa Román-Berdiel

A new type of fault relay zone that contrasts with the classical models of hard- and soft-linkage is described, based on the structural characterization of the relay zones at the eastern boundary of the Jiloca graben, as well as on a previous study of analogue modelling. These relay zones show abundant faults and fractures at map and outcrop scale that cut Neogene and Quaternary materials. Between the Sierra Palomera, Concud and Teruel faults, these ruptures define an along-strike pattern of recent fractures, more or less parallel to the macrostructures depending on the relative influence of the structural heritage and the biaxial extension regime active in the region. Transverse ruptures are absent within these relay zones. In contrast, the relay zone between the Calamocha and Sierra Palomera faults is characterized by along-strike minor faults at its southern sector, and transverse fractures at its northern sector that do not seem to propagate southwards. Previous studies defend that the main faults are independent structures from the geometric and kinematic point of view, although they undergo dynamic interaction. The described ruptures within the relay zones probably play an important role in such interaction: i) transferring part of the displacement, ii) accommodating stress perturbations, iii) triggering seismic events on another adjacent main fault, hypothetically resulting in alternating slip on both of them, as proposed for the Concud and Teruel faults. The Jiloca fault system is considered to be in a transient stage previous to linkage. The latter will probably occur in the future by propagation of one of the involved faults, giving rise to a final anastomosed fault pattern different from the final linkage geometries classically defined in the literature.

FT 2.14 – Héctor Perea **hperea@icm.csic.es**

FAULT AND FOLD SEGMENTATION AND COMPLEXITY: NEW INSIGHTS FROM 3D P-CABLE DATA OFFSHORE SOUTHERN CALIFORNIA

Hector Perea, James Holmes and Neal Driscoll

Often fault and fold segmentation and characterization of their kinematics and evolution in time is based on surficial geology and 2D seismic data. Despite many advances, 3D seismic data is required to understand how faults interact in space and time and the complexity of the fault systems. To achieve this objective, a high-resolution 3D Parallel Cable (P-Cable) seismic dataset was acquired along the Newport-Inglewood Rose Canyon (NIRC) fault. The NIRC is a complex right lateral strike-slip fault system that stretches for 120 km, mostly offshore, and parallel to the southern California coast. The Holocene fault slip-rate ranges from 1.5-2.0 mm/yr to 0.5-1.0 mm/yr, from south to north, according to onshore paleoseismological studies. An earthquake rupturing the entire length of the offshore system could produce a M7.3 earthquake and potentially impact around 20 million Southern California residents. The acquired offshore dataset images

the outer continental shelf and upper slope. The preliminary analysis of this high-resolution seismic volume has allowed mapping of several faults that offset different seismostratigraphic units. The mapping shows two main families of faults, some trending N-S to NNW-SSE and the others NE-SW, being the former the predominant. In addition, it reveals that the faults consist of a number of segments that may join at depth, but also that the NE-SW system acts as a structural boundary in the continuation in the N-S faults and folds. In conclusion, the 3D mapping of the geological structures along the NIRC system highlights the complexity and relationship between faults and folds in a shear zone.

PO 2.15 – Laura Peruzza **lperuzza@inogs.it**

MARCA-GEHN, A PROTOTYPAL MACROSEISMIC ARCHIVE OF FOUR CENTRAL AMERICA COUNTRIES

Laura Peruzza, Eliana Esposito, Giuseppe Giunta, Griselda Marroquín, Rosa Amelia García Castro, Rodolfo Torres, Douglas Antonio Hernandez, Sara Guevara, Edwin Nadir Castrillo, Carlos Rubi Tellez, David Monterroso, Pablo Santos, Tanya Ordóñez Martínez, Félix Enrique Rodríguez García, Maynor Ruiz, Carlos Tenorio, Abel Alexei Argueta Platero, Omar Flores, Alan Cosillo, Amilcar Roca, Claudio Cravos

In the frame of the activities of RIESCA Project ("Proyecto de formación aplicada a los Escenarios de Riesgo con la vigilancia y monitoreo de los fenómenos volcánicos, sismicos e hidrogeologicos en América Central", funded by the Agenzia Italiana per la Cooperazione allo Sviluppo, and coordinated by the University of Palermo) we agreed to build up a prototypal archive of macroseismic data points for the Central America countries involved in the project, namely, El Salvador, Guatemala, Honduras and Nicaragua. The objective of this collection is to establish a common, quality controlled seismological dataset, for checking, validating, and eventually updating the earthquake parameters for some damaging and destructive events. They will be integrated into new fault/area source characterization for seismic hazard purposes as well as into site-specific characterization of metropolitan areas. With collaborative efforts, a google form for inputting the data into a repository has been realized and tested in 2017. During 2018, the seismological working group has uploaded about 1500 intensity data-points of 60 earthquakes in a prototypal archive named MARCA-GEHN (Macroseismic Archive of Central América - Guatemala, El Salvador, Honduras, Nicaragua). We will present the general features of the database and some interesting case studies among the earthquakes collected.

FT 2.16 – Léa Pousse-Beltran **pousse@cerege.fr**

POST-SEISMIC DEFORMATION FOLLOWING THE 2016 NORCIA EARTHQUAKE (ITALY), AS REVEALED BY INSAR TIME SERIES

Léa Pousse-Beltran, Anne Socquet, Lucilla Benedetti, Marie-Pierre Doin, Magali Rizza, Nicola D'Agostino

The Mw 6.5 Norcia earthquake occurred on October 30, 2016 along the Vettore fault (Central Apennines). It was the largest earthquake that took place during the 2016-2017 Italian seismic sequence that started on August 24, 2016 with the Mw 6.0 Amatrice earthquake and lasted almost six months. . To quantify strain release and detect potential postseismic slow slip during the sequence, we produced time-series using 6-day repeat cycles of Sentinel-1A/1B SAR images. The images span almost two years for the ascending track (from July 2015 to June 2017), and span from October 2016 to February 2017 for the descending track. The produced time-series indicate that a centimetre-scale deformation took place during the 10 weeks following the Norcia earthquake, while no deformation was detected after Amatrice earthquake. Two areas of deformation have been detected: one in the Casteluccio basin (hanging wall of the Mt Vettore fault), and one in the southern extremity of the Norcia surface rupture in a structurally complex area where the activated normal Mt Vettore fault system cuts the Sibillini thrust system. In the Casteluccio basin, the deformation reaches 14.89 ± 1.32 mm in the ascending line of sight (LOS) on January 06, 2017. South of the Norcia surface rupture, the post-seismic deformation affects a smaller area, but reaches 29.98 ± 1.65 mm in ascending LOS. Pattern tracking of this southernmost deforming area indicates a logarithmic temporal decay consistent with postseismic deformation and afterslip along the Mt Vettore-Bove fault system. We estimate that this afterslip released a geodetic moment equivalent to a Mw 5.7 event. Our analysis suggests that the structurally complex area located south of the Norcia rupture is characterized by a conditionally stable friction. This geometrical and frictional barrier likely halted seismic slip propagation during the Amatrice and Norcia ruptures.

FT/PO 2.17 – Cristina Sánchez-Serra csserra@icm.csic.es

TSUNAMIGENIC STRUCTURES IN THE GULF OF CADIZ AND THE WORKFLOW FOR TSUNAMI HAZARD ASSESSMENT

C.S. Serra, E. Gràcia, R. Urgeles, S. Martínez-Loriente, L. Gómez de la Peña, S. Lorito, A. Piatanesi, F. Romano, F. Maesano, R. Basili and M. Volpe

The southwestern margin of the Iberian Peninsula, which includes the Gulf of Cadiz, is characterized by a present-day active deformation mainly driven by the NW-SE trending convergence (3.8-5.6 mm.yr-1) between the Nubia and Eurasia plates. The SW Iberian margin is a seismogenic area characterized by low to moderate magnitudes (Mw ≤ 5.5). In addition, this area hosts some of the largest earthquakes occurred in Western Europe, such as the 1st of November 1755 Lisbon Earthquake and tsunami (Mw ≥ 8.5). The active fault structures can be classified in two main families: a) WNW-ESE trending dextral strike-slip faults, and b) NE-SW trending thrusts faults. To characterize the seismogenic and tsunamigenic potential of each fault system, we develop several tsunami models. The workflow involves the following tasks: 1. Interpretation of the seismic profiles (in time) defining the traces of main active faults; 2. Mapping the trace of the faults using multibeam bathymetry; 3. Mesh of the fault surface and their respective horizons to generate a 3D model of the subsurface for each fault; 4. Conversion of the 3D model from time-to-depth assigning a velocity value (i.e. from available velocity models of the area) to the interval between horizons; 5.Defining the specific attributes for each fault, such as Length, Width, Depth, Strike, Dip and Rake; 6. Determine the maximum magnitude and slip for each fault. The maximum magnitude should be compatible with the length and the width previously defined, so we use the Leonard (2014) scaling-law; 7. Finally, the tsunami simulations for each fault have been run using "Tsunami-HySEA" software. We run two simulations for each fault, the first one considering the fault as an inclined planar surface and the second simulations used the 3D mesh.

FT/PO 2.18 – Petra Štěpančíková stepancikova@irsm.cas.cz

INTRAPLATE LATE QUATERNARY TECTONIC ACTIVITY OF THE MARIÁNSKÉ LÁZNĚ FAULT (CHEB BASIN, CZECH REPUBLIC) DOCUMENTED ON A SITE WITH SURFACE FAULT COMPLEXITY

Petra Štěpančíková, Tom Rockwell, Tomáš Fischer, Filip Hartvich, Petr Tábořík, Jakub Stemberk, Hamid Sana, Lucie Nováková

Mariánské Lázně fault (MLF) is a NW-SE striking, morphologically pronounced structure in western Bohemian Massif (Czech Republic), which controls the eastern limit of the Cheb-Domažlice graben. The northern segment of the MLF limits the Cenozoic Cheb basin on the east, which is superimposed on the western part of the NE-SW trending Eger Rift. The Cheb basin is well-known for present-day earthquake swarm seismicity (max. ML=4.6), Quaternary volcanism and mantle-derived CO2 emanations. We carried out 3D paleoseismic survey at the Kopanina site to decipher Quaternary tectonic activity of the MLF. We excavated 4 fault-crossing, 3 fault-parallel trenches, and 6 hand-dug microtrenches, which was preceded and accompanied by geophysical survey to extend geological information obtained from trenches laterally and more to the depth. The 2D and 3D geophysical survey included electric resistivity tomography and ground penetration radar. The trenches revealed a complex geology and deformation probably as a result of right-lateral transpression during Late Quaternary. The MLF seems to be expressed here by several fault splays active during different geological times. The youngest observed faulting occurred during two earthquakes of suggested minimum magnitude Mw=6.3–6.5 and displacing Holocene deposits of the age interval 5.3-1 ka BP. The latter earthquake occurred around 1000 years ago. First attempt to analyse the catalogues of historic earthquakes to match a recorded historic event suggests 998 AD with assessed M6.2 with epicentre near Chomutov (70 km from the trenching site). So it is a historical event and the youngest geologically proved surface faulting in central Europe reported so far, and crucial for re-assessment of seismic hazard.

PO 2.19 – Jack Williams **williamsj132@cardiff.ac.uk**

PARAMETERISING SEISMIC HAZARD IN REGIONS WITH LITTLE HISTORICAL OR INSTRUMENTAL SEISMICITY: LESSONS FROM DEVELOPING THE MALAWI RIFT ACTIVE FAULT DATABASE

Jack N Williams, Åke Fagereng, Luke NJ Wedmore, Juliet Biggs, Lachlan Wright, Donna Shillington, Christopher Scholz, Felix Mphepo, Zuze Dulanya, Hassan Mdala, Katsu Goda, Berhe Goitom

The 900 km long amagmatic Malawi Rift accommodates 1.8 ± 0.4 mm/yr extension at the southern incipient end of the Western Branch of the East African Rift System. However, Malawi's <60 year instrumental seismic record only accounts for ~ 0.3 mm/yr extension, which indicates the record is an incomplete and inappropriate dataset for characterising seismic hazard. Instead, a fault-based approach is desirable. To this end, we have developed the Malawi Rift Active Fault Database in accordance with Global Earthquake Model neotectonic fault database guidelines. Faults were mapped based on high-resolution digital elevation models, fieldwork, seismic reflection surveys, and legacy geological maps. Given a lack of chronostratigraphic constraints for past earthquakes, we define a fault as active if it shows evidence for displacement during the current East African Rift tectonic regime. Fault slip rates are assigned by partitioning rift-wide geodetic extension rates according to current theory on strain distribution between border and intrabasinal faults in continental rifts. From these rates, recurrence intervals are calculated using fault length-single event displacement relationships. Faults in the Malawi rift tend to be highly segmented, illustrated by the 2009 Karonga sequence of sequential M6 earthquakes on adjacent fault segments. However, we cannot exclude the possibility of past or future multi-segment ruptures. Thus, recurrence intervals are derived for both individual and whole fault multi-segment ruptures. This contributes to a large variability (>2 orders of magnitude) in recurrence intervals estimates, which will require careful consideration in future probabilistic seismic hazard models for the Malawi Rift.

<u>SESSION 3</u>: Earthquake fault rupture and slip complexities: How-To MODEL them in SHA

FT 3.1 – Roberto Basili **roberto.basili@ingv.it**

MODELING SEISMIC HAZARD OF SUBDUCTION ZONES: THE CASE OF THE CALABRIAN ARC, ITALY

Basili Roberto, Maesano Francesco Emanuele, Tiberti Mara Monica, Visini Francesco (INGV, Italy)

This work illustrates a contribution to the realization of the Italian seismic hazard map (MPS19) that will be released later this year. Specifically, we show the model of the Calabrian subduction zone (Italy). Here, we derive all the 3-dimensional geometric properties of the slab from Maesano et al. (2017) and then construct two independent models: one for the interface seismicity, and another for the intraslab seismicity. For the interface (18-40 km depth), the seismic moment rate is derived from the convergence rate considering the seismic efficiency. The seismic moment rate is then converted into the annual earthquake rate of a magnitude-frequency distribution (MFD). The b-value is assumed to be equal to 1. For the intraslab (20-440 km depth), we estimated the earthquake occurrence rates from the CPTI15 (Rovida et al., 2016) historical earthquake catalog. In evaluating the b-value we consider the magnitude dependency of completeness periods of the CPTI15 and partitioned the estimated earthquake rates uniformly for all the nodes of 3-dimensional grid. In both models, we use the Tapered Gutenberg-Richter (TGR) Pareto distribution. The corner magnitude of either MFDs is estimated from earthquake rupture scaling relationships compared with the reported magnitudes in the CPTI15. To evaluate the PSH we adopted two sets of GMPEs, a single GMPE for the interface, and a logic tree with two weighted GMPEs for the intraslab. - References: Maesano F. E., Tiberti M. M., Basili R. (2017), The Calabrian Arc: three-dimensional modeling of the subduction interface: Sci Rep, doi:10.1038/s41598-017-09074-8. - Rovida A., Locati M., Camassi R., Lolli B., Gasperini P. (2016), CPTI15, the 2015 version of the Parametric Catalogue of Italian Earthquakes, INGV, doi:10.6092/INGV.IT-CPTI15.

PO 3.2 – Ana Carvalho **xana.carvalho@lnec.pt**

IS IT AN ADDED-VALUE TO ASSESS PSHA USING DETERMINISTIC PHYSICS-BASED MODELS OR IT IS THE SAME IF USING GMPES BASED ON THE SAME MODELS?

A. Carvalho

The probabilistic-deterministic methodology (PDA) integrates PSHA with the high-frequency stochastic simulations for the prediction of peak and spectral ground motion parameters. Thus, some of the parameters that may affect the radiated energy in the near source and that are not usually considered by classical attenuation relations can be accounted for. Incorporating in the hazard spectrum specific features such as directivity and source parameters, it results in a more realistic characterization of hazard at a site which will be of extremely importance for improvements to the characterization of the response spectrum at a site. On the other hand, the development of stochastic based ground motion synthesis associated to a seismological finite-fault modeling is a worldwide approach that can be used for representation of future large magnitude earthquakes. This modelling technique is now being used to develop regional ground motions prediction equations (GMPES) in many regions of the world. Should these GMPES account for directivity and source parameters and could be used in a classical PSHA, leading to the same sigma (aleatory uncertainty) as a probabilistic-deterministic methodology integrated in PSHA? Herein the two approaches will be applied for mainland Portugal, and results will be compared and analysed.

RT 3.3 – Thomas Chartier **thomaschartier0@gmail.com**

REDUCING UNCERTAINTIES IN SEISMIC RISK ESTIMATES IN ISTANBUL BY COMBINING STATISTICS- AND PHYSICS-BASED APPROACHES

Thomas Chartier, Oona Scotti, Hélène Lyon-Caen, Keith Richards-Dinger, Jim Dieterich, Aurélien Boiselet

Calculating the magnitude and rate of earthquakes that can be expected along the North Anatolian Fault is the first step for assessing the seismic risk affecting the city of Istanbul, Turkey. In this study, we implement two complementary modeling approaches to assess the rate and magnitude of earthquakes that can be expected in the fault system. In the first approach earthquake rates are computed using the code SHERIFS (Seismic Hazard and Earthquake Rate In Fault Systems) which explores in a statistical manner an ensemble of rupture scenarios. The main assumption made in SHERIFS is that the magnitude frequency distribution (MFD) should respect an imposed shape at the system level. We set up a logic tree exploring hypotheses: a GR MFD shape and a shape tuned to the MFD shape of the catalog, which diverges from a GR shape. We also explore two sets of rupture scenario with different maximum magnitudes Mmax=7.7 and Mmax 8.0. The comparing the seismicity rates modeled with SHERIFS with the available data doesn't allow rejecting any of the hypotheses. In the second approach, earthquake rates are computed with RSQSim, a boundary element earthquake simulator based on the rate and state friction equation. The 10000 years long simulations run with RSQSim reproduce the observed MFD shape in the region and do not contain earthquakes larger than magnitude M~7.7. If to the first order the properties of RSQsim earthquakes (e.g. scaling laws and historical ruptures) are reasonably well reproduced, physics-based approaches still require validation. This notwithstanding, RSQsim results strongly suggest that the large uncertainties affecting seismic risk estimates in Istanbul could potentially be reduced by half in the future by combining the physics-based and statistical approaches.

FT 3.4 – Álvaro González **alvaro@geonaut.eu**

IMAGINING THE LARGEST TECTONIC EARTHQUAKES ON EARTH

Á. González

Subduction zones, the largest continuous faults on Earth, have generated the largest recorded earthquakes. The maximum magnitude of tectonic earthquakes occurring globally would be logically determined by the largest earthquake ruptures in subduction interfaces. Unfortunately, there has been very limited success at defining meaningful segment boundaries

or barriers in subduction zones which may act as persistent rupture limits, so the overall maximum magnitude is not properly constrained (e.g. Kagan & Jackson, Geophys. J. Int, 2016). In this presentation it is considered, as the worst scenario, the complete rupture of each subduction zone in a single earthquake. The area of each subduction interface is calculated from its geometry and seismogenic depths, as detailed in the Slab2 model (Hayes et al., 2018). The magnitude and displacement are extrapolated from this area using up-to-date scaling relationships (Thingbaijam et al., Bull., Seism. Soc. Am., 2017). According to these results, the extreme magnitudes obtained would be due to the extreme assumed rupture areas, while average displacements would be similar to (or even smaller than) the maximum displacements already observed in giant (M>9) earthquakes. The overall maximum magnitude resulting from this exercise is then used as a putative upper limit for truncating the global magnitude-frequency distribution, fitted using data from the ISC-GEM and Global CMT catalogues. Such a fit is compared with others which do not use an upper truncation. In any case, geometrical constraints on earthquake rupture are evidenced by the statistically significant departure from a Gutenberg-Richter law for the largest recorded earthquakes (e.g. Serra & Corral, Sci. Rep, 2017; Corral & González, Earth & Space Sci., 2019).

FT 3.5 – Mohamed Hamdache m_hamdzache@hotmail.com

IMPROVEMENT OF SEISMIC HAZARD ASSESSMENT FOR NORTHERN ALGERIA BASED ON FAULT PARAMETERS MODELING

M. Hamdache, A. Yelles Chaouche and J. A. Pelaez

Modeling seismic source zones is a fundamental step of probabilistic seismic hazard assessment. The most recent progress attempt to include the potential of active faults by introducing an accurate estimation of the rate of earthquakes on the fault, in order to improve the seismic hazard evaluation. In this study modifications to the source-zone model for the Maghrebian region are introduced by including some known faults located around the Mitidja basin as the Zemmouri fault responsible of one of the most recent damaging earthquake in northern Algeria, which occurred on May 21, 2003 (Mw6.9), or the fault network around the Chelif basin, the site of the October 1980 (Ms7.3) earthquake. The slip rate, the rupture geometries and magnitude-frequency are modeled and introduced in the seismic hazard assessment which allows us to capture the recurrence of large-magnitude event. The proposed model includes area and fault sources. In the first step of the study, the maximum possible magnitude, the rate of exceedance, the b-value of the Gutenberg-Richter magnitude-frequency, the maximum and minimal stress (SHmax, SHmin) are used to characterize the different zone-source of the model. The obtained parameters for each source-zone, are combined with attenuation equation of ground motion, in terms of PGA and Sa, to derive seismic hazard values for different return periods at different sites in northern Algeria. The results are presented in terms of seismic hazard curves for PGA and Sa and Uniform hazard Spectra (UHS). The performed study allows us to derive through disaggregation analysis the different scenarios and their contributions to the seismic hazard evaluation at a given site.

FT 3.6 – Marie Jacottin marie.jacottin@irsn.fr

USING GPS DATA TO CONSTRAIN MAXIMUM MAGNITUDE IN SUPER-SLOW-DEFORMATION REGIONS

M. Jacottin, S. Mazzotti, O. Scotti

The Armorican Massif (NW of France) is a slow deforming intraplate region. Nevertheless destructive earthquakes have occurred in the past, such as the 1799 Bouin earthquake (Mw > 6.0) located in the South of the Armorican Massif. Does this event, the largest known in this region in the last 1000 years, represent the maximum magnitude that can occur in the future? Can geodetic data help us better constrain the maximum magnitude? In order to answer these questions, we used a combination of GPS data (including the RENAG network) to compute a smooth 3D GPS velocity field on a 40 km-spacing grid. We defined the geometry of the fault network that composes the South Armorican fault system based on the Active Fault Data Base developed at IRSN (Jomard et al., 2017). 3D GPS velocity vectors were projected on the rupture planes of the fault system to estimate individual fault slip rates. This characterized fault system was then run in SHERIFS (Seismic Hazard and Earthquake Rates In Faults System), a python code that converts fault slip rates into seismicity rates by distributing the moment rate budget over a collection of rupture scenarios defined by the user. Preliminary analyses indicate a first-order agreement between modeled seismicity rates and those deduced from the historical and instrumental catalog. This suggests that geodetic data may be a useful input to constrain the maximum magnitude. Further analyses are required to take into account the epistemic and aleatory uncertainties on the fault seismogenic depths and 3D geometries, scaling laws and, most importantly, on the GPS-based slip rates which have a strong impact on the maximum magnitude estimations.

FT/PO 3.7 – Judith Mariniere judith.mariniere@univ-grenoble-alpes.fr

PROBABILISTIC SEISMIC HAZARD ASSESSMENT FOR THE SUBDUCTION INTERFACE IN ECUADOR: EXPLORATION OF ALTERNATIVE SOURCE MODELS AND IMPACT ON HAZARD ESTIMATES

J. Mariniere, C. Beauval, J.-M. Nocquet, H. Yepes

The modeling of earthquake recurrence for subduction sources in PSHA studies is not as advanced as for crustal shallow sources inland. The analysis of the models proposed for the different subduction regions in the world (e.g. South America, Alaska, Taiwan, Japan, New Zealand) show that there is no consensus on how to use the information available to estimate probabilities of occurrence of earthquakes over future time windows. The aim of the present work is to apply the different models on the same subduction interface source zone, the Andean subduction in Ecuador, and to analyze and compare the resulting hazard estimates. Earthquake catalogs available are used, as well as geodetic models derived for the zone (Nocquet et al. 2014, 2017; Chlieh et al. 2014). Uncertainties on the catalog-based seismic rates are explored, testing alternative magnitude conversion equations and different declustering algorithms. Uncertainties on the seismic moment budget estimated from geodesy are also explored, integrating information on the spatial partitioning between seismic and aseismic slip. Both the characteristic earthquake model and the Gutenberg-Richter recurrence model are tested. Taking into account the 3D geometry of the slab, these alternative models are coupled with ground-motion prediction equations providing probabilistic seismic hazard estimates for the Ecuadorian coast.

FT 3.8 – Simona Miccolis simona.miccolis@uniba.it

GEOLOGIC VERSUS GEODETIC SLIP RATE: THE CASE OF MARSICANO FAULT, CENTRAL APENNINES

Miccolis S., Carafa M. M. C., Di Lorenzo C., Kastelic V., Di Naccio D.

Understanding the crustal strain accumulation and fault slip rates is a critical task for geodynamics and seismic hazard assessment. Recently, the geodetic measurements have been successfully introduced into fault slip rate calculations by converting the GPS-derived strain rates into well constrained fault slip rates. These slip rate estimates are alternative to the geologic ones which are mainly based on the measurement of the offset on the fault slope profile, surface exposure dating, geomorphic investigations or on paleoseismological data. Anyway, the compatibility and the agreement between geodetic and geologic slip rates remain poorly investigated, especially for slow deforming regions. Given these circumstances, in this work we focus on Marsicano Fault determining both geodetic and geologic slip rates. This fault is part of the Sangro Valley Fault System and according to some authors it hosted the 1984 Barrea earthquake (M=5.8). Using permanent and semi-continuous GPS registrations and available SHmax azimuths, we perform a kinematic modeling to determine a range of slip rate for Marsicano Fault. Then, starting from the peer-reviewed scientific literature, we collect and analyze geological data to provide the best combined probability density function of long-term slip rates. Results are expressed as mode, median, mean, 95% confidence limits and standard deviation. The method requires the convolution of probability density functions of age and offset, previously estimated by the algorithm. Finally, we quantify the misfit between the geologic and geodetic slip rate estimates and we show the effect of such misfit on earthquakes rate calculation.

FT/PO 3.9 – Fiia Nurminen **fiia.nurminen@unich.it**

PROBABILISTIC FDH MAPS FOR THRUST FAULTS: MODELLING BASED ON NEW EMPIRICAL REGRESSIONS FOR DISTRIBUTED FAULTING

Fiia Nurminen, Francesco Visini, Bruno Pace, Alessandro Valentini, Paolo Boncio

Probabilistic fault displacement hazard analysis (PFDHA) is used for characterizing the expected fault rupture hazard and the amount and distribution of co-seismic fault displacement. The approach was seen incomplete especially regarding the distributed faulting (DR) in thrust faulting environments. The purpose of this work is to create a probabilistic model for predicting the surface fault displacement in thrust fault environments. The analysis is based on the empirical database gathered from 11 historical thrust earthquakes, which is used in the analysis of the spatial distribution of DR and establishing the attenuation relationships to the amount of dislocation for the increasing distance from the principal fault (PF). The general methodology follows the one of the traditional PFDHA, but especially for the analysis of the distributed fault rupturing several methodological adjustments were done for obtaining a statistically robust model that could be used for prediction purposes. The model utilizes the surface geometry of the fault to be modelled, the parameters derived from the calculation of the probability of the occurrence, and the expected amount of distributed faulting. It computes the probability of the secondary rupturing exceeding a certain displacement level, or the amount of the DR displacement with a given probability, and it enables the location specific analysis of the seismic hazard. The model is applied to the Suasselkä post-glacial fault (Finland) for a scenario where the fault ruptures for its total length (Mw ~7.0), and the probability of surface displacement is analysed in the surroundings of the fault. The model created here can be applied to any well-known mapped thrust fault with relatively simple geometry.

PO 3.10 – Laura Peruzza **lperuzza@inogs.it**

TOWARD A FAULT2SHA COST ACTION

Peruzza, L.

A poster will introduce the new proposal for a COST action, to be submitted in Sept. 2019.

FT/PO 3.11 – Marco Santulin **msantulin@inogs.it**

SEISMIC HAZARD COMPUTED FOR CENTRAL ITALY COMBINING BOTH PROBABILISTIC AND DETERMINISTIC APPROACHES

Santulin M., Moratto L., Tamaro A.

In this study the seismic hazard is estimated for the Campotosto Lake area, adopting probabilistic (PSHA) and deterministic (DSHA) approaches. PSHA has been conducted according to the seismotectonic probabilism, in the software formulation of Crisis2015. A simple logic tree with only three branches has been considered to take into account of the epistemic uncertainty in the attenuation models applied. The new zonation presented in this study (narrow sources based on new and updated geological and seismological data) has been developed as a branch of the logic tree that will be used for the new Italian seismic hazard map (MPS19). In Italy, the strongest earthquakes releasable have ultra-millenary recurrence period. A probability of exceedance of 2% in 50 years, corresponding to the 2475 years return period, can therefore be considered reasonable to compute a reference UHRS for evaluating the representativeness of the MCE spectrum. The disaggregation of the probabilistic seismic hazard, computed for this return period, gives us the source (in terms of a magnitude-distance couple) that most influenced the seismic hazard of the considered study sites; this source is then parametrized with a pseudo-dynamic finite-fault model and used as input in the broadband deterministic simulations. In the DSHA the results are very scattered and the spatial variability of the ground motion is strong due to different inputs (e.g. various slip distributions) that influence the shaking computed for near field receivers placed close to each other. Our simulations highlight the importance of the vertical component that in the near field cannot be ignored because potentially affected by shaking values comparable or superior to horizontal components.

PO 3.12 – Oona Scotti **oona.scotti@irsn.fr**

FAULT2SHA

Fault2SHA Executive Committee

An overview of FAULT2SHA activities.

PO 3.13 – Syed Tanvir Shah **stshah.geo@gmail.com**

FAULT-BASED PROBABILISTIC SEISMIC HAZARD ASSESSMENT (PSHA) IN EXTENSIONAL AND COMPRESSIONAL TECTONIC SETTINGS: EMPHASIS ON COMPLEX SOURCE GEOMETRY AND ACTIVITY RATE CHARACTERIZATION

Syed Tanvir Shah, A. Arda Özacar and Zeynep Gülerce

Extensional and compressional tectonic regimes display complex fault geometries, hence pose a challenge for accurate representation of seismogenic sources and constraining source parameters for fault-based PSHA. Extensional regimes are often characterized by multiple sets of inclined faults and paucity of individual slip rates; causing considerable ambiguity in calculation and distribution of activity rates. Similarly, the subduction zone complexities involving megathrust interface, intra-slab zone and accretionary prism faults lead to enhanced uncertainties in seismic source characterization. In this study, detailed PSHA with sensitivity analyses for various enigmatic parameters are carried out for part of the Western Anatolian Extensional Province (WAEP) and the Makran Subduction Zone. For WAEP, alternative approaches utilizing geodetic and seismic data are employed to determine the activity rates for sub-regions which are later partitioned among fault systems using surface morphology and segment length. As a result, a procedure that provides weighted, maximum and minimum peak ground acceleration (PGA) maps incorporating activity rates from all methods is established to evaluate and minimize the bias on hazard estimates. For the Makran megathrust, alternative magnitude distribution models, range of dip amounts and subsurface extents defining the maximum rupture width are tested. Truncated exponential model resulted in ~10% higher PGA for 475 years return period, but composite magnitude recurrence model provided a better match with the seismicity. For short return periods, gentler and deeper-extending interface geometries resulted in higher PGA values towards inland along accretionary wedge, due to their influence on rupture dimensions and source-to-site distances.

RT 3.14 – Alessandro Valentini **alessandro.valentini@unich.it**

AN UNSEGMENTED WASATCH FAULT ZONE MODEL: IMPACT ON PROBABILISTIC SEISMIC HAZARD ANALYSIS

Alessandro Valentini, Christopher B. DuRoss, Bruno Pace, Ryan D. Gold, Francesco Visini, Richard W. Briggs, and Edward H. Field

The Wasatch fault zone (WFZ) is one of the most studied normal fault systems in the world and one of the most hazardous in the United States as it has paleoseismic evidence of repeated Holocene surface-faulting earthquakes and occurs within the densely urbanized Wasatch Front region. Here, we develop an earthquake rupture forecast for the WFZ that quantifies the 50-year probability of all potentially damaging earthquakes above Mw 6.2. Our goal is to evaluate the impact that models of fault segmentation (i.e., hard limits on rupture extent) have on seismic hazard. We evaluate the long-term rate of ruptures on the WFZ, adapt standard inverse theory used in the Uniform California Earthquake Rupture Forecast 3, and implement a segmentation constraint where ruptures that cross primary structural complexities are penalized. Penalized ruptures have low rates or are removed from the inversion. We develop and test three segmentation models, including (1) a segmented model in which ruptures are confined to individual segments, (2) a penalized model where some multi-segment ruptures are allowed, and (3) an unsegmented model in which all ruptures are allowed and none are penalized. Our results show that mean seismic hazard is highest in the segmented model because of more frequent moderate-magnitude (Mw 6.2–6.8) ruptures and lowest in the unsegmented models. We evaluate the change in hazard curves and maps from these segmentation models, test how other parameters such as slip rate and magnitude-scaling relations affect our results, and conclude that segmentation exerts a primary control on seismic hazard. Our study demonstrates the need for additional geologic observations of prehistoric rupture extent as well as methods to include this information in hazard assessments.

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FRESH: AN APPROACH FOR COMPUTING EARTHQUAKE RUPTURES AND RATES OF OCCURRENCES IN FAULT SYSTEMS

Francesco Visini

Use of faults in seismic hazard models allows capturing the recurrence of large-magnitude events and therefore improve the reliability of probabilistic seismic hazard assessment (PSHA). In the past decades, fault segmentation provided an important framework for quantifying fault-based PSHA. However, in the last years, complex coseismic ruptures (e.g. 2010 M 7.1 Canterbury, 2012 Mw 8.6 Sumatra, 2016 Mw 7.8 Kaikōura, 2016 Mw 6.5 central Italy) imposed to pay particular attention to the treatment of all possible combinations of rupture scenarios for PSHA. Here we present a new methodology to model rate of ruptures along fault systems, based on a floating rupture approach called FRESH: Floating-Rupture for Seismic Hazard. It represents an alternative to SHERIFS, an approach recently proposed to go one step beyond the strictly-segmented one commonly used in Europe. Differences in the approaches are related to the way slip rate, rupture geometries and MFD are modelled. We demonstrate that FRESH, as well as SHERIFS, is able to solve for the long-term rate of ruptures with resulting PSHA that reflect the fault system geometry and slip rates, without any assumption on segment boundaries. Now that multi-fault rupture approaches are available, simplistic, uniform slip rate approaches along complex fault systems should be avoided to the benefit of local data collection, which should be strongly encouraged.

FT 3.16 – Pouye Yazdi **pouye.yazdi@upm.es**

ANALYSIS OF THE SEISMIC SERIES FOLLOWING THE LARGE THRUST EARTHQUAKE OF 18 APRIL 2014, PAPANOA, MEXICO (M7.3)

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We analyze the M7.3 2014 Papanoa (Mexico) seismic series. This sequence is located along the tectonic interface, in the northwestern part of the Guerrero seismic gap. The Papanoa mainshock caused considerable damage and losses in nearby coastal areas, reaching PGA values of 0.9 g for soft soil sites at the city of Papanoa. In this study, we compute the Coulomb failure stress changes due to the mainshock and the two largest earthquakes with M6.6 and M6.2 in 8 and 10 May 2014, respectively. The distribution of aftershock hypocenters highly coincides with areas showing positive stress changes along the interface geometry. We apply epidemic-type aftershock sequence modeling to study the aftershock productivity and the contribution of elastic loading as the source of aftershock generation. Modeling results suggest an increase of background seismicity rates following the Papanoa mainshock. This is in agreement with studies that correlate the Papanoa rupture plane with the weakened coupling area of the oceanic and the continental crust close to the low slip zone in Guerrero. Additionally, we compute ground motion exceedance rates using magnitude-dependent, smoothed seismicity rates. Different periods and declustering approaches are applied to evaluate the contribution of interface sources to ground motion exceedance rates at selected sites at Papanoa and Zihuatanejo cities. The results show a slight increase of expected accelerations for different exceedance probabilities at these coastal cities.

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A MULTI-CYCLE EARTHQUAKE SIMULATOR FOR PROBABILISTIC EARTHQUAKE RUPTURE FORECASTING

Olaf Zielke, Martin Mai

An important aspect in SHA is the formulation of earthquake rupture models, constraining the probability of earthquakes to exceed a certain size within a region and time frame. Earthquake rupture models are primarily informed by observations from instrumental seismology, paleoseismology, or historical accounts. Unfortunately, these records are generally too short, incomplete, and potentially ambiguous –limiting their value to SHA. It is desirable to complement observational constraints with other data sets, derived from different approaches. One approach is the numerical simulation of long earthquake sequences. Here, we want to introduce a newly developed multi-cycle earthquake rupture simulator –a computational framework for the generation of earthquakes sequences. This physics-based rupture simulator adheres to elastic deformation, stress transfer, and fault friction. It is based on the boundary element method, utilizing analytical formulations by Nikkhoo and Walter (2015) for triangular dislocations in an elastic half-space. The adopted fault parameterization allows to quickly define arbitrarily complex fault systems along which earthquakes may spontaneously occur. Long-term stressing rates are defined via "boundary condition faults" that enclose the modeled faults. Three different approximations for friction are currently implemented, enabling to investigate the system's response to the specific characteristics of those approximations. Our earthquake simulator is not the first of its kind. A number of groups have taken similar approaches in the last two decades, most notably UC riverside with RSQsim. With our simulator we want to provide an alternative tool for computationally generating physics-based earthquake rupture forecasts that can complement observations.

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Appendix: Instruction for the authors

A flash talk is a very short presentation lasting only a few minutes, sometimes referred as lightning talk. Usually lightning talks are delivered by different speakers in a single session, called a data blitz. The goal of lightning talks is to articulate a topic in a quick, insightful, and clear manner. These concise and efficient talks are intended to grab the attention of the audience, convey key information, and allow for several presenters to share their ideas in a brief period of time. Common formats of lightning talks include PechaKucha and Ignite, and involve a specific number of slides that are automatically advanced at fixed intervals. Prepare the lightning talk to make your points clearly, and rid the presentation of non-critical information. A single computer will be running the presentation program by all speakers.

Posters will be visible throughout the duration of the workshop –maximum size **A0**, **vertical (portrait)**. If you want to try something new, check the format proposed here https://www.youtube.com/watch?v=1RwJbhkCA58