PATA Days-2022 : International Workshop on Paleoseismology, Active Tectonics and Archeoseismology - 2022

25-30 sept. 2022 Aix-en-Provence (France)

Table of contents

Earthquakes Geology and General Contributions

Contributions of lithospheric strength, mantle hydration and slab flexure to seismic localization in the southern Central Andes

Constanza Rodriguez Piceda * [3,2,1], Magdalena Scheck-Wenderoth [2,4], Mauro Cacace [2], Judith Bott [2], Ya-Jian Gao [5], Frederik Tilmann [2,6], Manfred Strecker [3]

[3] University of Potsdam – Germany
[2] German Research Centre for Geosciences - Helmholtz-Centre Potsdam – Germany
[1] School of Geography, Earth and Environmental Sciences [Plymouth] – United Kingdom
[4] RWTH Aachen University – Germany
[5] Karlsruher Institut für Technologie – Germany
[6] Free University of Berlin – Germany

The subduction zone of the Nazca plate along the southern Central Andes orogen (SCA-29◦S-39◦S) is characterized by widespread seismic activity in the subducting slab, the overriding plate and along the subduction interface. Past research has primarily focused on linking the distribution of seismicity with the stress regime on discrete faults and inherited basement fabrics at local scale. However, the contribution of lithospheric strength, which depends on its bulk structure, composition and thermal state, has not been addressed in detail. In this contribution, we systematically explore the relationship between the long-term rheological state and the distribution of seismicity of the southern Central Andes by computing the mechanical strength of the region based on existing 3D models of the thickness, composition, and temperature of the lithological components that constitute the upper and lower plates of the subduction system. In addition, we investigate the effect of fluid-mediated reactions (i.e., sediment consolidation at the plate interface and metamorphic reactions in the oceanic crust and mantle) regarding lower-plate seismicity by analysing the Vp/Vs ratio from a recent seismic tomography model derived from Full Waveform-Inversion. Finally, we address the role of flexural stresses as a response to changes in the subduction geometry in order to explain a seismic cluster in the region where the subducting slab attains a sub-horizontal angle. Our work highlights the importance of performing a detailed analysis of the thermal and rheological configuration of the lithosphere to better assess the causative mechanisms governing the spatial distribution of seismicity in the Andean orogen.

Keywords: subduction, seismicity, lithospheric strength, Andes

*Speaker

Neotectonic of Papua, Indonesia

Astyka Pamumpuni * [2,1], Benyamin Sapiie [1], Danny H. Natawidjaja [3], Irwan Meilano [2,1]

[2] Center for Earthquake Science and Technology ITB – Indonesia
[1] Institut Teknologi Bandung – Indonesia
[3] Research Centre for Geotechnology, Indonesian Institute of Sciences – Indonesia

Interactions between the Australian, Pacific, Eurasian, and Philippine Plate generate complicated geology of Papua Islands. Those interactions still occur today and produce high seismic activity in the area. Several active faults result from the tectonic activity in Papua, e.g., Sorong Fault Zone, Manokwari Fault Zone, Yapen Fault Zone, Mamberamo Fault Zone, Lengguru Fold Thrust Belt, Papua Fold Thrust Belt, Tarera-Aiduna Fault, Gauttier Thurst, New Guinea Trench. Powerful earthquakes with more than 7 Mw have been recorded in the earthquake catalog even in the last 1-3 decades. Tsunami wave often follows earthquake, e.g., Biak 1996. The characteristic of segmentation and activity for each fault of Papua is still unclear. The source of these earthquakes is yet to be defined.

This neotectonic study of Papua utilizes remote sensing data, bathymetry, seismic section, seismicity, surface geology, and GPS data. The methods used in this study are tectonic geomorphology, active fault mapping, GPS analysis, seismic interpretation, and focal mechanism analysis. The result suggests that the Pacific-Australia interaction has been partitioned into shortening and shear interactions. This study provides an active fault map, including fault segmentation in Papua. The active fault of Papua can be divided into structural domains, i.e., Bird's Head, Yapen Fault Zone, Mamberamo-Nawa Hill Fault Zone, Papua Fold Thrust Belt, and Bird's Neck. Faults kinematic in Papua result from northwest moving Pacific Plate and Australia Plate interaction. GPS velocity data shows that Pacific Plate motion is mainly accommodated by the Mamberamo Fault Zone and Nawa Hill in the north, stepping to the left to Tarera-Aiduna Fault Zone in the south, connected through Wapoga Trough. New Guinea Trench and Manokwari Fault Zone also accommodate Pacific Plate motion in the northernmost part of Papua.

Keywords: Papua, neotectonic, bathymetry, geomorphology

*Speaker

From emergent to blind: The Active Andean Thrust Front in the Southern Precordillera, Argentina

Victoria Alvarellos *† [1], Costa Carlos H. [2], Andrés Richard [3,4], Andrés Folguera [1,5], Lucía Sagripanti [1]

[1] Instituto de Estudios Andinos “Don Pablo Groeber” (IDEAN), CONICET-Universidad de Buenos Aires, Buenos Aires – Argentina
[2] Universidad Nacional de San Luis – Argentina
[3] Departamento de Geología, Universidad Nacional de San Luis, San Luis – Argentina
[4] CONICET-CCT San Luis – Argentina
[5] Facultad de Ciencias exactas y Naturales, Universidad de Buenos Aires, Buenos Aires – Argentina

At the southern Pampean flat-slab, the Quaternary active deformation is concentrated on the easternmost thrusts of the Southern Precordillera along the Las Peñas-Las Higueras hill (32° 10'-32° 45'). This range is bounded by Las Peñas thrust, which emplaces Cenozoic sedimentary rocks over a suite of Quaternary alluvial deposits. The Neogene mountain building related to this thrust activity decreases toward both range tips. The geomorphic signature of the Las Peñas thrust at the northern tip vanished beneath the piedmont alluvium through a complex geometry related to lateral ramps. At the southern range end, the thrust front corresponds to a transposed east-verging anticline, which becomes blind in the study area South of Baños Colorados creek. North of this creek, the Las Peñas thrust is propagating towards the piedmont, affecting well preserved Quaternary stratigraphy. Migration through the piedmont is by splays that develop anticlines, which are successively incorporated into the hanging wall as the splays migrate eastward. The piedmont exposes fault scarps, such as bulldozing scarps, affecting different terrace levels which could indicate that these fault propagation folds are active. Therefore, this passage from emergent to blind thrusting implies different approaches for addressing the characterization of fault activity. North of Baños Colorados creek, the main thrust and younger piedmont splays emerge with associated terraces folding. Hence, high-resolution topographical techniques and paleoseismological studies in natural or man-made exposures are ideal for their study. The neotectonic analysis at the blind thrust section relies mostly on the modeling and retrodeformation of geometric markers, such as alluvial surfaces. The field evidence so far analyzed suggests a drastic change in thrust activity within a few kilometers along the trace, which may indicate that the slip rate is not uniformly distributed along with the thrust.

Keywords: Active Tectonics, Orogenic front, Andean thrusts, Southern Precordillera Argentina, Surface ruptures, Blind thrusts

*Speaker
†Corresponding author: vicuu-a@hotmail.com

Near-surface upward termination of the contractional strike-slip ruptures: Evidence from paleoearthquakes of the Yangsan Fault in SE Korea

Youngbeom Cheon *† [1], Chang-Min Kim [1], Jin-Hyuck Choi [1], Sangmin Ha [2], Seongjun Lee [2], Taehyung Kim [1], Hee-Cheol Kang [2], Moon Son [2]

[1] Active Tectonics Research Center, Korea Institute of Geoscience and Mineral Resources – South Korea
[2] Department of Geological Sciences, Pusan National University – South Korea

Dynamic strike-slip earthquake ruptures propagate on pre-existing faults and show a wide range of deformation styles along and across the fault-strike at and near the ground surface. The strike-slip rupture processes and resultant deformation in shallow subsurface are influenced by various geological and tectonic factors. We present a new example of the termination of strike-slip paleoearthquake ruptures in near-surface regions on the Yangsan Fault, South Korea, based on multi-scale structural observations. Paleoearthquake ruptures occur mostly along the boundary between the mature fault core and damage zone (striking NNE–SSW with an eastward dip of > 75○). It is one of the active seismogenic faults in the Korean Peninsula and was the causative fault of the 2016 Gyeongju Earthquake (Mw 5.5), the largest instrumental earthquake recorded in South Korea. Since the earthquake, we discovered various late Quaternary surface ruptures at several excavation sites within the fault zone. The ruptures propagated rapidly upward to shallow subsurface along a < 3-cm-wide specific slip zone with a dextral-slip sense, along which the deformation mechanism is characterized mainly by granular flow in near-surface region. The ruptures either reach the surface or are terminated within unconsolidated sediment below the surface. In the latter case, the rupture splays show westward bifurcation, and their geometry and kinematics show a change to a NNW–SSE strike with a low-angle dip and a dextral-reverse oblique-slip sense in the strata. We suggest that the upward termination of the contractional strike-slip ruptures is controlled by (1) unfavorable horizontal angle between the strike of pre-existing fault and imposed tectonic stress, (2) relative magnitudes between the overburden stress and the minimum horizontal stress changed at the superficial level (_˜200 m in depth), and (3) physical properties of unconsolidated sediment, having no anisotropy to constrain rupture distribution, and having low inter-granular cohesion to cause dispersion of deformation.

Keywords: Yangsan Fault, Paleoearthquake, Upward termination, Contractional strike slip rupture

*Speaker
†Corresponding author: cheonyb@kigam.re.kr

Paleoseismological trenching and tectonic geomorphology reveal an active fault with evidence for repeated large Holocene earthquakes in Papua New Guinea

Beau Whitney * [1], James Hengesh [2], Frederic Rossi [3], Cedric Duvail [3], Önder Yönlü [4], Manel Labidi [3]

[1] Beau Whitney – Whitney Geologic, Fugro France SAS – France
[2] Interface Geohazard Consulting – United States
[3] Fugro France SAS – Fugro France SAS – France
[4] Fugro GB – United Kingdom

Papua New Guinea (PNG) occupies one of the most active and tectonically complex plate boundary collisions on Earth, and experiences frequent large-magnitude earthquakes and rapid rates of subduction and mountain building. The fundamental geology of the region has been studied for over a century, but little is known about the earthquake history prior to _˜1900. We present new geological and geomorphological data that constrain the magnitude and frequency of paleo-earthquakes on a previously unconstrained plate boundary thrust fault near the Purari River in the Gulf Province of southern PNG. A paleoseismological investigation of this fault identified evidence for repeated earthquakes of _˜Mw 7.3 to 8.0. Based on radiometric dating and oral histories from villages along the fault, the most recent earthquake occurred approximately 450 years ago. This event ruptured the ground surface and caused coastal uplift of a Holocene strandplain complex. The timing of the event coincides with village re-settlement and re-initiation of the regionally important Hiri trading voyages. The results shed light on what may have caused abrupt changes in trading activities and village movements in the region over the past few thousand years.

Keywords: tectonic geomorphology, marine terraces, surface rupture

*Speaker

Interactions between active tectonics and gravitational deformation along the Billecocha fault system (Northern Ecuador): insights from morphological and paleoseismological investigations

Hervé Jomard * [1], Diana Saqui [2], Stéphane Baize [1], Alexandra Alvarado [3], Benjamin Bernard [2], Laurence Audin [4], Sylvana Hidalgo [2], Daniel Pacheco [2], Mario Ruiz [2], Monica Segovia [2]

[1] Institut de Radioprotection et de Sûreté Nucléaire – Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – France
[2] Instituto Geofisico Escuela Politécnica Nacional – Ecuador
[3] Instituto Geofisico Escuela Politécnica Nacional – Ladrón de Guevara s/n PO Box 17-01-2759 Quito, Ecuador
[4] Institut des sciences de la Terre (ISTerre) – OSUG, INSU, Université Joseph Fourier - Grenoble I, Université de Savoie, IFSTTAR, IRD, CNRS : UMR5275 – BP 53 38041 Grenoble cedex 9, France

The Billecocha plateau (4000 m a.s.l.) lies in the high elevation Ecuadorian Andes volcanic arc and overhangs by 2000 m above the interandean valley. The area is heavily affected by active faulting characterized by straight, sharp and discontinuous scarps within a 6km wide and 24km long corridor. The instrumental seismicity recorded around the BFS is low, however, a M≈7,2 earthquake heavily struck the region in 1868.
With the aim to discuss the kinematic and coseismic nature of the encountered deformations as well as the seismogenic character of the billecocha fault system (BFS), we performed (1) morphological analysis to map and quantify evidence of active faulting and (2) paleoseismological investigations across the longer segment of the fault system.

In three trenches, we show that surface deformations are coseismic in origin during the Holocene, the last paleoseismic event being compatible in date with the 1868 earthquake. In addition, some of the enlightened paleoseismic events could have occurred in relationship with volcanic eruptions of the surrounding volcanoes.

However, while paleoseismological evidences suggests that regional tectonics could be involved, the geomorphological signature of the BFS at the mountain scale is compatible with the development of deep-seated gravitational deformations (DSGSD), suggesting an interaction between boundary (tectonic, volcanic) and body forces (gravity, post-glacial rebound).

*Speaker

Keywords: Ecuador, Active tectonics, Paleoseismology, deep seated gravitational slope deformations (DSGSD)

Where are seismites formed? New insights from lacustrine sediments with implications for palaeoseismology

Ian G Alsop [1], Ram Weinberger [2], Tsafrir Levi [2], Shmuel Marco *† [3]

[1] Department of Geology and Geophysics, School of Geosciences, University of Aberdeen, Aberdeen – United Kingdom
[2] Geological Survey of Israel, Jerusalem – Israel
[3] Department of Geophysics, Tel Aviv University – Israel

Earthquakes leave their marks on sedimentary rocks as faults that offset the strata and as seismites, which in lake deposits appear as soft-sediment deformation, associated with slumps and mass transport deposits (MTDs). These are generally considered to form when unlithified sediment moves downslope under the influence of gravity. However, our observations on the Lisan Formation (palaeo-Dead Sea sediments), reveal bed-parallel slip (BPS), where neighboring beds slide past one another along bedding planes, without offsetting the stratigraphy. We use pre-existing fault planes as markers for identifying and determining the sense and amount of slip. In addition to slippage, we show that shear exerted by a seismogenic single failure event may concurrently create surficial and sub-surface deformed 'intrastratal' horizons at different stratigraphic levels in a 'synchronous failure model'. The sub-surface intrastratal deformation is typified by detachment-bound folds and thrusts that are marked by repetitions of stratigraphy across the upper detachment surface, fluidized sediment that intrudes upwards into the overlying sequence, together with abrupt truncations of older faults developed in the overburden above the detachment. Hence, in lacustrine palaeoseismic records, sub-surface deformation can be significantly younger than the depositional age of beds it affects, thereby weakening age-depth correlations used to estimate the timing of palaeo-earthquakes.

Keywords: seismites, earthquakes, faults, Dead Sea

*Speaker
†Corresponding author: shmulikm@tau.ac.il

Paleoseismic characteristics along the southern Ulsan Fault Zone, SE Korea

Ohsang Gwon *† [1], Sambit Prasanajit Naik [1], Kiwoong Park [1], Young-Seog Kim [1]

[1] Pukyong National University – South Korea

Although it is still debatable that the Korean peninsula is seismically stable or not, historical and paleoseismological data suggest that the Ulsan Fault Zone is a highly prone area to large earthquakes in Korea. Therefore, it is important to understand the paleoseismic characteristics of the Ulsan Fault to reduce future earthquake hazards. It is known that the NNW-trending Ulsan Fault is a reverse dominant fault. However, the studies to understand the characteristics of paleo-earthquakes along the Ulsan Fault are limited, especially in the southern segment of the fault. In this study, we evaluated the paleoseismic characteristics for the southern segment of the Ulsan Fault. For this study, first of all, we traced the lineament of the fault based on geomorphic analysis using light detection and ranging images(LiDAR), aerial photographs, and unmanned aerial vehicles(UAVs). Thereafter, excavation surveys were conducted using data from field and electrical resistivity survey. In the Site 1(Hogye), the sediment stratigraphy was divided into seven layers based on grain size and type, roundness of gravel, degree of sorting and color. The measured cumulative vertical displacement was at least 6 m. The last faulting event occurred after 161±6 ka. In the Site 2(Chail), the sediment stratigraphy was divided into five layers. Two east dipping faults were identified and the net slip associated with the last faulting event was calculated from the apparent vertical displacement of the displaced sediment and unconformity (_˜1.41 m). The moment magnitude was estimated based on the maximum displacement (_˜ Mw 6.6). The last faulting event occurred between 2.1±0.1 - 88±6 ka. These parameters indicate that the high seismic potential with a long recurrence interval of the fault zone, which will be useful for seismic hazard assessment around the southern Ulsan Fault Zone.

Keywords: Ulsan Fault Zone, reverse fault, net slip

*Speaker

†Corresponding author: osgwon@pukyong.ac.kr

Major California faults are smooth across multiple scales at seismogenic depth

Anthony Lomax *† [1], Pierre Henry [2]

[1] ALomax Scientific, Mouans-Sartoux, France – ALomax Scientific – France
[2] Aix Marseille Univ, Aix-en-Provence, France – CNRS : UMR7330, Institut de recherche pour le développement [IRD] : UMR161, INRAE, Collège de France, Centre de Recherche et d'Enseignement de Géosciences de l'Environnement [CEREGE] – France

Surface traces of earthquake faults are typically complex and segmented on multiple scales. At seismogenic depth the detailed geometry of faults and large-earthquake rupture is mainly constrained by earthquake locations. Standard, absolute-timing earthquake location is usually too diffuse to constrain multi-scale fault geometry and smoothness, while differential-timing relocation, giving fine-scale precision, typically shows smooth seismicity mainly on offset segments of up to a few kilometers in length. NLL-SSST-coherence, an enhanced, absolute-timing earthquake location procedure, iteratively generates traveltime corrections to improve multi-scale precision (e.g. study area extent to _˜1km) and uses waveform similarity to further improve fine-scale precision (e.g. sub-km). Here we apply NLL-SSST-coherence to relocate recent large-earthquake sequences and background seismicity along strike-slip faults in California. Remarkably, the relocated seismicity at seismogenic depth along major faults and surrounding large-earthquake ruptures often defines smooth, narrow, planar or arcuate, near-vertical surfaces across the sub-km to 10's of km scales. Along 50km of the San Andreas fault around Parkfield, differential-timing relocations show a twisting and kinked fault surface containing offset segments; in contrast, NLL-SSST-coherence relocation defines a smooth, planar, near-vertical fault. Our California relocations suggest that smooth faulting across multiple scales is characteristic of mature fault zones and a condition for rupture growing into a large earthquake, that smoothness and curvature of faults influences large-earthquake initiation, rupture and arrest, and that planar and smooth alignments of background seismicity can delimit zones of earthquake hazard. Additionally, the results support use of planar or smoothly curved faults for earthquake rupture modeling, and provide further evidence that surface traces and offsets of strike-slip fault zones may reflect complex, shallow deformation and not directly simpler, main slip surfaces at depth.

Keywords: fault geometry, seismicity, fault smoothness, rupture physics, hazard, California

*Speaker
†Corresponding author: alomax@free.fr

Seeking seismogenic sources for paleoearthquakes in the Alps: clues from a DSGSD in the Italian Southern Alps.

Franz Livio * [1], Maria F. Ferrario [1], Andrea Zerboni [2], Rivka Amit [3], Guido Mariani [4], Elisa Martinelli [1]

[1] Università degli Studi dell'Insubria – Italy
[2] Università degli Studi di Milano – Italy
[3] Geological Survey of Israel – Italy
[4] Università di Cagliari – Italy

Triggering mechanisms and causative processes of deep-seated gravitational slope deformations (DSGSD) in Alpine and high mountain areas include among others post-glacial debuttressing, earthquake-induced ground shaking or co-seismic surface faulting. Distinguishing between climatic or tectonically driven factors is challenging since faults and fracture systems can play both an active and/or passive role in the process initiation. We applied an integrated approach, including morpho-structural analysis, geologic field survey, a paleoseismological approach flowed by radiocarbon dating and detailed sedimentological analysis, to a DSGSD located in the Cavargna Valley (N Italy), an area that was never occupied by extensive ice cover in the Upper Pleistocene and Holocene.
We attempted to identify the triggering mechanism for the Cavargna Valley DSGSD by considering the historical earthquake catalog, a dataset of offshore lacustrine paleoseismological indicators and regional flood chronology.
We conclude that a seismic triggering is likely for the onset of the DSGSD during the initial Middle Holocene, based on the spatio-temporal clustering of offshore evidence, with a possible source located in an area lacking known historical seismicity or active faults, pointing to a possible knowledge gap in the seismotectonics of the Alps. Later evolution and successive pulses in the activity of the Cavargna Valley DSGSD (Late Holocene), instead, seem to be correlated to regional proxies of climatic changes, showing a possible association with periods of increased surface instability.

Keywords: seismic landslides, DSGSD, triggering factors, European Alps

*Speaker

Seismogenic structure of the 1976 Ninghe (North China) Ms6.9 earthquake and its tectonic implications

Shengxue Lei *† [1,2], Jianbo Liu [1], Ray Weldon‡ [3], Shuangqing Liu [1], Hu Qiu [1], Richard Walker [2], Tian Song [1], Chengguo Yan [1]

[1] Tianjin Earthquake Bureau, Tianjin – China
[2] Department of Earth Sciences, Oxford University – United Kingdom
[3] University of Oregon – United States

On November 15, 1976, three and a half months after the deadly Tangshan earthquake, a *Ms* 6.9 earthquake occurred in the county of Ninghe, eastern Tianjin, North China, causing tens of deaths and huge economic losses to this region. The Ninghe earthquake, the southernmost major aftershock that occurred along the southern Tangshan fault zone, is the largest earthquake ever recorded in the Tianjin area. Numerous studies have been carried out on the Tangshan earthquake and the Tangshan fault zone during the last four decades; however, little research has been performed on the Ninghe earthquake. Because Tianjin is economically developed with a population of $>$ 14 million, detailed study of the seismogenic structure of the Ninghe earthquake has enormous significance for seismic hazard assessment and long-term earthquake prediction in Tianjin. In this study, based on a geomorphic survey of possible ground rupture, relocation of small earthquakes, composite borehole exploration to assess subsurface offsets, and intensity survey results of former researchers, the following conclusion are made: (1) the seismogenic structure of the Ninghe earthquake is unlikely to be a NW-trending fault (including the Jiyunhe fault, which is generally accepted to be the source), but more likely to be a NE-trending structure, such as the Fuzhuang-Gaozhuang fault; (2) a "restraining bend" associated with right-lateral slip across a left step between the Fuzhuang-Gaozhuang and Tangshan faults, well explains the occurrence of two thrust events following the initial main strike-slip event during the Tangshan main shock; (3) To date, the Fuzhuang-Gaozhuang fault is the sole known Holocene-active fault exposed at the surface in the Tianjin area. With a potential seismic capacity of magnitude _˜7, the Fuzhuang-Gaozhuang fault poses the most significant seismic hazard in eastern Tianjin; thus we suggest more detailed research on this fault.

Keywords: Ninghe earthquake, Tangshan earthquake sequence, seismogenic structure, Fuzhuang, Gaozhuang fault, Jiyunhe fault, Tangshan fault zone

*Speaker
†Corresponding author: studentlei2000@163.com
‡Corresponding author: ray@uoregon.edu

A New Look at the Ground Rupture of the Motagua Fault in the 1976 Guatemalan Earthquake along the Caribbean-North American Plate Boundary

Tina Niemi * [1], Trenton Mcenaney [1], Jonathan Obrist Farner [2], Omar Flores [3]

[1] University of Missouri - Kansas City – United States
[2] Missouri University of Science Technology – United States
[3] Universidad de San Carlos de Guatemala – Guatemala

The 1976 magnitude 7.5 Guatemala earthquake ruptured the Motagua fault along the North American-Caribbean plate boundary in one of the most devastating earthquakes in the 20th Century that resulted in over 23,000 fatalities. For a major plate boundary, very little is known about the long-term rupture history of the Motagua fault and the probability of future earthquakes hazards it poses to the large and growing population in Guatemala City. In this study, we sought to relocate sites along the 1976 Motagua fault rupture by analyzing archival material from George Plafker of the U.S. Geological Survey who collected data on the effects of the earthquake within days of the event. The data included 1250 original 35 mm slides, numerous annotated 1:50,000 scale topographic maps, several hundred aerial photographs, a 1978 field trip guidebook, and various other original documents that are only available in paper format. These historical documents denote the severity of the event, with primary and secondary strike-slip faulting, landslides, liquefaction, and structural damage. Maps, photographs, and reports from the 1976 Guatemalan earthquake were digitally scanned into a georeferenced database. In July 2021, we made a reconnaissance trip to relocate the 1976 Motagua fault earthquake rupture. Many of the offsets measured in the 1976 earthquake were in pastures and along dirt roads and are no longer visible. The offsets of the concreted-lined canal at Gualán and the Zacapa asphalt highway are still extant. In some locations, the fault has a clear geomorphic expression of repeated late Quaternary slip with sag depressions and fault scarps crossing alluvial fans and terraces. However, in other locations, the 1976 fault rupture is difficult to locate and sites lack evidence of long-term Quaternary deformation. These data suggest a developing transform plate boundary with strain likely partitioned onto subparallel faults.

Keywords: ground rupture, historical earthquakes, Caribbean, Central America

*Speaker

Seismogenic faults, seismo-lineaments, and related thermal waters in the Colca basin, S Peru

Krzysztof Gaidzik * [1], Andrzej Tyc [1], Jerzy Żaba [1], Justyna Ciesielczuk [1], Andrzej Paulo [2], Malwina Wiesek [3], Carlos Benavente Escóbar [4], Laurence Audin [5]

[1] Institute of Earth Sciences, University of Silesia, Sosnowiec, Poland – Poland
[2] Faculty of Geology, Geophysics and Environmental Protection, AGH University of Science and Technology, Kraków, Poland – Poland
[3] Faculty of Natural Sciences, University of Silesia, Sosnowiec, Poland – Poland
[4] Instituto Geológico Minero y Metalúrgico (INGEMMET) – Peru
[5] Institut des sciences de la Terre (ISTerre) – OSUG, INSU, Université Joseph Fourier - Grenoble I, Université de Savoie, IFSTTAR, IRD, CNRS : UMR5275 – BP 53 38041 Grenoble cedex 9, France

Crustal faults in the overriding plate above the subducting slab are usually less studied when compared to the subduction zone itself and omitted and/or underestimated in seismic hazard assessments. However, even smaller seismic events with epicenters originated along crustal faults due to the shallow focal depth and closeness to the human settlements can be equally hazardous, producing analogous if not more fatalities and economic losses than some of the megathrust earthquakes. Even though pronounced in satellite imagery, these geologic structures in the Colca River basin are still not properly studied. We propose a multidisciplinary approach combining morphotectonic analysis of crustal faults, field survey, focal mechanism review, seismo-lineaments computation, together with hydrogeochemical and isotopic analysis of springs and geysers. Morphotectonic analysis and field observations concur with the principally W- to NW-striking seismo-lineaments and highlight the surface expressions of seismogenic faults in the Colca basin together with focal mechanisms of crustal earthquakes. The applied scaling relationships suggest a seismic potential for earthquakes of maximum moment magnitudes up to 6.8–6.9 for segments of the recorded crustal structures. The active fault network in the Colca basin is a crucial agent in the complex hydrogeological thermal system. Thermal springs and geysers show a clear spatial correlation with active and seismogenic crustal W- to NW-tracing normal and strike-slip faults. These might act as a barrier to infiltrating meteoric waters, pathways to hydrothermal solutions and gases assisting in meteoric water heating, and passages for heated waters ascending into the surface. The reactivation of identified structures can be related to the following sources of stress: 1) strain partitioning in the oblique subduction zone, 2) crustal seismicity induced by megathrust earthquakes, 3) extension in the most upper part of the uplifting area above the subducting slab, and 4) volcanic activity.

Keywords: Crustal fault, thermal water, tectonic geomorphology

*Speaker

Paleoseismic study of the XEOLXELEK–Elk Lake fault: A newly identified Holocene-active fault in the northern Cascadia forearc near Victoria, British Columbia, Canada

Nicolas Harrichhausen *† [1,2], Theron Finley [3], Kristin D Morell [2], Christine Regalla [4], Scott E K Bennet [5], Lucinda J Leonard [3], Edwin Nissen [3], Eleanor Mcleod [3], Emerson M Lynch [4], Guy Salomon [3], Israporn Sethanant [3]

[1] Institut des Sciences de la Terre – Université Grenoble Alpes – France
[2] Department of Earth Science [Santa Barbara) – United States
[3] School of Earth and Ocean Sciences [Victoria] – Canada
[4] Northern Arizona University [Flagstaff] – United States
[5] United States Geological Survey (USGS) – United States

We present results from a paleoseismic study documenting Holocene rupture of the XEOLXELEK–Elk Lake fault in the metropolitan region of Victoria, British Columbia, Canada. Victoria is located in the northern Cascadia forearc, where the greatest seismic hazard is thought to result from rupture of the Cascadia subduction zone megathrust. However, recent studies highlight the additional hazard from surface-rupturing earthquakes on low slip-rate (_˜1 mm/yr) faults in the forearc. Due to low deformation rates, recent late Pleistocene glaciation that eroded tectonic geomorphic features, and thick vegetation, mapping these faults and determining their earthquake rupture histories has proved difficult. We used high-resolution airborne lidar topography data to overcome these challenges and identified the XEOLXELEK–Elk Lake fault, a newly recognized fault delineated by a topographic scarp that deforms Quaternary glacial landforms and sediments _˜10 km north of downtown Victoria. Electrical resistivity tomography surveys and paleoseismic trenching across this scarp reveals glacial-marine sediments deformed by a northeast-vergent fault-propagation fold above a 45○ – 55○ southwest-dipping reverse fault. Forward modelling of fault-propagation folding resulting from slip on a _˜50○ dipping fault suggests _˜3.2 m of reverse slip could produce the observed deformation. We combined five geologically plausible OxCal models of radiocarbon dates of charcoal collected from deformed sediments and an overlying colluvial wedge to model a rupture age. The average of the probability density functions for earthquake ages from each model indicates a single rupture that most likely occurred between 4.7 ka and 2.3 ka. This age does not immediately follow deglaciation, suggesting the earthquake was unrelated to glacial isostatic rebound. The magnitude of the slip during this rupture combined with the projected dip of the XEOLXELEK–Elk Lake fault

*Speaker
†Corresponding author: n.harrichhausen@univ-grenoble-alpes.fr

beneath Victoria's city center, implies the fault poses a significant hazard to local infrastructure and the region's _~400,000 inhabitants.

Keywords: High resolution topography, Paleoseismic trench, Electrical resistivity, OxCal model, Fault propagation fold, Cascadia

The Uplift History along the Mishmi Thrust within the Eastern Himalayan Syntaxis during Neogene and Quaternary time

Chandreyee Goswami Chakrabarti * [1,2], Erhan Gulyuz [1], Belligraham Narzary [3], Manoj Jaiswal [3], Fatih Karaoğlan [4]

[1] Ustav Structury a Mechaniky Hornin – Czech Republic
[2] University of Calcutta – India
[3] Indian Institute of Science Education and Research Kolkata – India
[4] Institute of Geology of the Czech Academy of Sciences – Czech Republic

The North-East corner of India is bounded by India-Eurasia and India-Burmese collision systems in the north and the south-east, respectively, forming the Eastern Himalayan Syntaxis (EHS). Upward movement along the NW-SE trending Mishmi Thrust (MT) at the eastern part of EHS placed the granitic rocks with the metasedimentary cover over the Quaternary rocks. The spectacular Manabhum anticline has also formed during Quaternary as a ramp anticline over a splay of Mishmi Thrust in its foreland region. We have prepared geological-geomorphological maps of the area.

Our work aims to understand Neogene to recent uplift/exhumation rate of basement rocks along the Mishmi thrust which is hitherto unknown from this part of the Himalayas. We have used low-temperature thermo-chronology (LTT) and OSL dating techniques for the Neogene to early Quaternary and late Quaternary time intervals.

The geological section and OSL ages of different sedimentary horizons from different heights forming the Manabhum hill indicate that the core of the hill hosts the oldest sediments of the anticline. OSL age of that sediment indicates that they were deposited around _˜0.22Ma. The sampling site of the OSL age is at the height of 175m from the present-day flood plain. This implies a 3.2mm/year uplift rate for the core of the anticline which locates on one of the active splays of the Mishmi thrust. In addition to the late Quaternary uplift rate of the foreland region, the full-vector LTT ages from a single point of the hanging wall of the thrust are represented by 4.83±0.68 Ma (Zircon Helium – _˜200◦C), 1.85±0.27 Ma (Apatite Fission Track- _˜110◦C) and 1.34±0.5 Ma (Apatite Helium- _˜70◦C) ages. Based on a 33◦C/km geothermal gradient, the average uplift rate of the hanging block varies between 0.91 to 2.33mm/year since about the last 5 Ma.

Keywords: Himalayas, Uplift rate, Thermochronology, OSL

*Speaker

Capable or not? The intriguing case of the Pescopagano fault in the area of the 1980, Mw 6.9 Irpinia earthquake, southern Italy

Luigi Ferranti * [1], Francesco Iezzi [1], Alberto Bacchiani [1], Salvatore Buoninfante [1], Felice Menna [1], Monica Sposato [1], Vincenzo Di Fiore [2], Daniele Bellini [3], Alessandro Citterio [3], Roberto Calabrò [3], Claudio Pasqua [4]

[1] Dipartimento di Scienze della Terra, dellÁmbiente e delle Risorse – Italy
[2] CNR-ISPC - Istituto di Scienze del Patrimonio Culturale – Italy
[3] Edison SpA – Italy
[4] FrosioNext – Italy

The identification of capable faults often relies on the presence of hanging-wall scarps developed after the LGM (_˜15±3 ka). However, this approach can have severe pitfalls in the absence of independent evidence of recent activity (e. g. paleoseismological surveys), particularly in areas of recent change of tectonic regime and complex structural setting, such as the Southern Apennines of Italy.
For the purpose of a major infrastructure planning, we studied the _˜1.5 km long Pescopagano fault (PF), a segment of the extensional fault system that ruptured during the 1980, Mw 6.9 Irpinia earthquake. The PF lies above the blind antithetic fault that failed 40 sec after the main shock of the seismic sequence, and it is considered active and capable of producing surface ruptures.

The PF shows a rather degraded fault scarp, with a limited (1.5 m high x 5 m wide) exposure of the fault plane. The finding of a _˜10 cm high ribbon at its base induced further investigations to inquire involvement of the fault during the 1980 or past earthquakes through high-resolution seismic profiles and paleoseismological trenching.

The seismic profiles did not show appreciable offsets of the subsoil in the fault hanging-wall over the first 20 m depth. Paleoseismological trenches document that _˜6 ka BP colluvial deposits seal the fault. In addition, older fluvial gravels and marsh clays (possibly ranging from Middle Pleistocene to LGM) onlap over the fault scarp and no faulting occurs in the fault hanging-wall.
Our findings suggest that the PF has not released surface-rupturing earthquakes at least for the last 6 ka, and presumably for longer. Dating of the older units will allow us to better define the temporal activity of the PF, and to elucidate the tectonic context in which the fault grew.

*Speaker

Keywords: Active and Capable faults, Paleoseismological trenches, Southern Apennines, Irpinia 1980 earthquake fault system

New suggestion for the regulation of safe separation distance from active faults based on damage characteristics

Young-Seog Kim *† [1,2], Yeji Hong [1], Kwangmin Jin [3]

[1] Active Fault Earthquake Hazard Mitigation Institute – South Korea
[2] Major of Environmental Geosciences, Pukyong National University – South Korea
[3] Korea Institute of Geoscience and Mineral Resources – South Korea

Large earthquakes produce strong ground motions and surface ruptures, resulting in extensive damages and loss of lives. Because most large earthquakes are generated by the reactivation of pre-existing active faults, it is crucial to make active fault map. However, it is not easy to set up a standard for the safety regulation to the areas with a high probability of surface ruptures around active faults based on produced active fault maps, although it is necessary for anti-seismic design for constructions. Therefore, in this study, we suggest a new idea for the separation distance for safety based on previous studies and damage characteristics, especially considering for Korean tectonic situation. We classified the safe separation distance into three levels according to the regulation purpose from a active fault. First, zone 3 is defined as a wide notice zone to inform residents and property owners about the risk of earthquake hazards. Second, zone 2 is defined as a medium survey recommendation zone to recommend geological survey and seismic reinforcement when a development is planned within the area. Third, zone 1 is defined as a construction avoiding zone to strongly regulate the new construction of important facilities. In addition, this study also considered fault types and damage characteristics. For dip-slip faults, the safe separation distance for the hanging wall is suggested twice as wide as the footwall. For strike-slip faults, tip and linkage damage zones are considered and suggested to be establish 1.5 times wider than that of the main fault wall zone. Other controlling factors(e.g. rock property, expected earthquake magnitude) be considered as local factors when we have enough information on them. Therefore, establishing systematic regulation procedure for the safe separation distance based on fault types and damage characteristics is important to reduce earthquake hazards and to save unnecessary costs in earthquake-prone areas.

Keywords: active fault, earthquake rupture hazard, surface rupture, safe separation distance.

*Speaker
†Corresponding author: ysk7909@pknu.ac.kr

LIKELIHOOD OF PRIMARY SURFACE FAULTING: A SEQUEL

Marco Pizza *† [1], Maria Francesca Ferrario [1], Frank Thomas [1], Giorgio Tringali *

[1], Franz Livio [1]

[1] Università degli Studi dell'Insubria – Italy

Surface faulting is a common phenomenon for crustal earthquakes and is an important source of localized hazard for buildings and infrastructures. The assessment of this hazard is based on empirical datasets. The reference dataset was created almost 30 years ago (Wells and Coppersmith, 1993); we believe it is now timely an update of the dataset and the derived regression: to this end, we analyze recent seismicity with the aim of assessing the likelihood of primary surface faulting as a function of magnitude. The analysis of 915 global earthquakes is currently ongoing; the events have any type of kinematics, Mw between 5.5 and 7.9, hypocentral depth lower than 20 km, and occurred between 1992 and 2018. We built a homogeneous dataset in which, for each earthquake, Mw values, hypocentral depth, fault geometry and kinematics, and especially evidence of primary surface faulting are included. Input data derive from the ISC-GEM earthquake catalogue and the dataset compilation is achieved through analysis of published literature. In most cases the obtained data are certain and unequivocal, in other cases, especially for events with Mw

Keywords: earthquake, surface faulting, fault, seismic hazard.

*Speaker

†Corresponding author: m.pizza@uninsubria.it

Vertical slip-rate on the Shibetsu fault zone in the most eastern part of Hokkaido, Japan

Takashi Azuma * [1]

[1] Geological Survey of Japan, AIST – Japan

The Shibetsu fault zone is a NE-SW trending reverse fault along the southeastern margin of the Shiretoko Peninsula. Along this fault zone, This area is one of the most active volcanic zone and there are several calderas, which erupted catastrofic eruptions during Middle to Late Pleistocene and early Holocene. Flexural scarps are recognized on the fluvial fans, which were produced in the last glacial period or rather older age. Vertical slip-rate of this fault zone are estimated as ca. 0.3 m/ky based on amount of vertical displacement by using DEM data and age of fans inferred from tephrochronology in this area.

Keywords: Shibetsu fault zone, Hokkaido, slip rate, tephrochronology

*Speaker

Active faulting, earthquakes, and geomorphology of the Main Kopetdag fault, Turkmenistan

Richard Walker * [1], Geldy Begenjev [2], Yevgeniy Bezmenov [2], Nicholas Dodds [3], Christoph Grutzner [4], Neill Marshall [3], Edward Rhodes [5], Zahra Mousavi [6]

[1] Department of Earth Sciences [Oxford] – South Parks Road, Oxford OX1 3AN , UK, United Kingdom
[2] National Academy of Sciences – Turkmenistan
[3] University of Oxford – United Kingdom
[4] University of Jena – Germany
[5] University of Sheffield – United Kingdom
[6] University of Zanjan – Iran

We present results from a study of the active faults defining the margins of the South Caspian Basin, which is itself an enigmatic deep-water basin that appears to move relative to adjacent parts of Iran and Eurasia. We report on recent field-based estimates of the slip rates of the Main Kopeh Dagh (MKDF) strike-slip fault in Turkmenistan, which forms the boundary between stable Eurasia and the eastern parts of the Caspian block. This slip-rate estimate, along with other from the eastern Alborz of NE Iran, allow us to determine the rates and directions of motion relative to both Iran and Eurasia. Comparison of the present-day fault slip-rates with cumulative bedrock displacements across the faults, and also with independent geological estimates of mountain building where available, allow us to comment on the onset of the presently active deformation in the basin interior and within the mountain ranges that surround it. Despite large destructive earthquakes in 1948 in Ashkabad, and a series of deep earthquakes in the eastern Caspian lowlands, the MKDF overall shows an absence of earthquakes both in recent times and in history. We uncover evidence for large earthquakes that have occurred along the MKDF within the last 1000 years, showing that the MKDF is capable of producing large earthquakes, and also showing that the historical record in this part of Iran is not complete over the Medieval period. We are aided in our study of the MKDF by the very well preserved landscape, which preserves lateral offsets of amounts ranging from single-event offsets of 5-7 m, through to large-scale cumulative displacements of _˜1 km.

Keywords: Strike, slip, historical earthquake, slip rate, tectonic geomorphology

*Speaker

Signatures of 16th and 19th centuries paleo-earthquakes along the Himalayan Frontal Thrust (HFT), NW Himalaya, India: Implications to Seismic Hazard Assessment

Javed Malik *† [1], Mahendrasinh Gadhavi [2], Asmita Mohanty [3], Mitthu Dhali [4], Sambit Naik [5]

[1] Indian Institute of Technology Kanpur – India
[2] L. D. College of Engineering, Ahmedabad 380015. Gujarat. INDIA – India
[3] National Institute of Advance Sciences (NIAS), Bengaluru 560012 – India
[4] Department of Earth Sciences, Indian Institute of Technology Kanpur. Kanpur 208016. UP. INDIA. – India
[5] Active Fault and Earthquake Hazard Mitigation Research Institute, Pukyong National University, Busan, S KOREA – India

The Himalayas, one of the most seismically active regions in the world, experienced several damaging earthquakes in the recent past. Historical data (limited) and paleoseismic studies indicate that some portions of the Himalayas did not rupture during the historical time and have the potential to host major earthquakes. The paleoseismic study was conducted in the meso-seismal zone of the 1905 (Mw7.8) Kangra earthquake, NW Himalaya. Two trenches (ABT1 and ABT2) excavated across the Hajipur Fault (HF2) – an imbricated fault of Himalayan Frontal Thrust (HFT) near Asparbadaliya revealed signatures of at least three paleo-earthquakes, displacing/deforming young Quaternary deposits along NE dipping thrust fault strands (F1 and F2). Exposed stratigraphy in trenches and Optically Stimulated Luminescence (OSL) calibrated/modeled ages suggest that Event I occurred at around BCE 50 - CE 400; Event II was during CE 1450-1650, and Event III at around CE 1720-1840. A larger interval of _˜900-1000 years between Event-I and Event-II suggests that Event-II was a great earthquake with 8.0^{3}Mw$\leq$8.5 – correlated with the CE 1555 earthquake reported from Kashmir with a rupture length of _˜400-450 km, extending from Kashmir to Chandigarh. Event-III which occurred with an interval of 200-300 years was a large earthquake with a magnitude 7.5^{3}Mw$\leq$Mw8.0, and a rupture length of _˜200-250 km. We propose that the irregular recurrence interval could be attributed to variation in the distribution of fault system between HFT and Main Central Thrust (MCT) in NW (_˜100 km) and Central as well as NE Himalaya (_˜40-50 km), suggesting heterogeneity exists along the arc.

Keywords: Himalayan Frontal Fault (HFT), Active Fault, Northwest Himalaya, Paleo, earthquakes, Irregular recurrence interval.

*Speaker
†Corresponding author: javed@iitk.ac.in

New paleoseismic data for the characterization of the seismic potential in a complete transect of the Alhama de Murcia Fault (SE Spain)

Marc Ollé *† [1], Octavi Gómez-Novell [1,2], Domitille Dufour [3], Júlia Molins-Vigatà [1,4], Stéphane Baize [5], Raquel Martín-Banda [6], Juan Miguel Insua-Arévalo [4], María Ortuño [1], Raimon Pallàs [1], Giorgi Khazaradze [1], Eulàlia Masana [1]

[1] RISKNAT Research Group, Geomodels institute. Dpt. of Earth and Oceans Dynamics. Faculty of Earth Sciences, University of Barcelona, 08028 Barcelona, Spain – Spain

[2] DiSPUTer, Università degli Studi "Gabriele d'Annunzio" Chieti-Pescara, 66013 Chieti, Italy – Italy

[3] Dpt. of Geosciences, Ecole Normale Supérieure, PSL Research University, 75230 Paris, France – Dpt. of Geosciences, Ecole Normale Supérieure, PSL Research University, 75230 Paris, France – France

[4] Dpt. of Geodynamics, Stratigraphy and Paleontology, Complutense University of Madrid, 28760 Madrid, Spain – Spain

[5] IRSN, 92260 Fontenay-aux-roses, France – IRSN, 92260 Fontenay-aux-roses, France – France

[6] Dpt. of Geoscientific Research and Prospective, Instituto Geológico y Minero de España, 28040 Madrid, Spain – Spain

The Alhama de Murcia Fault (AMF) is one of the main seismogenic faults in the Eastern Betics Shear Zone (EBSZ). Its important contribution to the seismic hazard of the region has been clearly demonstrated by several authors. Between Lorca and Totana, the fault is composed of multiple branches that have their own contribution in terms of seismic history and slip-rate. A previous study constrained most of the activity of the fault by carrying out a paleoseismic analysis in four of the five most important branches in this sector and, therefore, producing the first paleoseismic transect analysis in the area summing up the contribution of each of them to the main fault at depth. However, an additional branch was not included in the transect: the N2a-AMF. In this work, we focussed on this branch with the aim to improve and complete its contribution and obtain the final parameters of the Alhama de Murcia Fault in this area (El Saltador-La Hoya). We made a detailed geomorphologic study in order to map N2a-AMF precisely and to select a suitable site for a paleoseismic trench. We also refined the mapping of N2b-AMF, which has been trenched previously, to better understand the relationship between these two antithetic branches. In our new trench, we observed clear evidence of recurrent deformation (a minimum of three morphogenetic events) on the most recent units, which implies that N2a-AMF has had activity at least during the upper Pleistocene (dating is in course). In this work we present the preliminary results of our ongoing investigation. We expect these new results to be helpful to complete the paleoseismic transect previously made in the AMF and therefore to contribute to a more realistic seismic hazard model in the region.

*Speaker

†Corresponding author: 99.olle.m@gmail.com

Keywords: AMF, EBSZ, paleoseismology, geomorphology, seismic hazard

Quaternary deformation along the Western Andean Front between 35○ and 37○ S, Chile: insights from morphometric analysis

Jorge Adrian Oviedo-Reyes *† [1,2], Joaquín Cortés-Aranda‡ [1,2], Andrés Tassara [1,2], Alfonso Fernández [1], Daniel Melnick [2]

[1] Universidad de Concepción – Chile
[2] Millennium Nucleus the Seismic Cycle along the Subduction Zones, CYCLO – Chile

The Western Andean Front (WAF) is a landscape comprising the region of the western edge of the Central and Southern Andes, ˜15○ S to ˜38○ S. Recently was demonstrated at ˜33○S the WAF is constrained on its western edge by the San Ramon fault. This structure is part of a proposed fault system that controls the mountain front from 15○S to ˜38○S, known as the West Andean Thrust (WAT). Nevertheless, towards the south of 35○S, unpublished data suggests that WAF has been uplifted during the Upper Pleistocene to Holocene timespan. Considerable geomorphological evidence of active tectonic is several scarps on recent deposits in the study area. We highlight the morphometric distinction of the most active tectonic segments of the WAT between 35○S and 37○S. Our semi-quantitative approach from morphometric analyses computed topographic parameters from DEM, obtaining the sinuosity of the piedmont-junction (Smf Index), the morphology of the valleys (Vf index), and the change of slopes on the trunk channels (SL index). The Smf/Vf/SL data indicate moderate to high tectonic activity along NE and NW-trend faults. The tectonically active segments of the WAF have been associated with uplift rates greater than 0.5 m/ka, while moderately active segments with lower uplift rates between 0.05m - 0.5m /ka. The morphotectonic elements and results obtained from the ratio Smf/Vf data suggest two related mountain fronts between the locality of Huépil and the city of Linares: firstly, an internal mountain front moderately tectonically active and, secondly, an external mountain front tectonically active dominated by NE-striking fault scarps over recent deposits (e.g., Catillo Fault, Huépil Fault). Finally, the faulting style for the study area obtained from Smf/Vf ratio suggests a double-vergence orogen with a tectonically active western edge and NW-trending tear faults accommodating the different blocks of the mountain front resulting in a Thrust Front Migration.

Keywords: Western Andean Front, landscape, Thrust Front Migration, morphometric analyses

*Speaker
†Corresponding author: jadrianoviedo@gmail.com
‡Corresponding author: joacortes@udec.cl

Mendocino Triple Junction, Humboldt County, California: Terraces and Tectonics in the latest Quaternary

Jason Patton * [1], Mark Hemphill-Haley [2], Ashley Streig [3]

[1] jason r patton – United States
[2] Mark Hemphill-Haley – United States
[3] Ashley Streig – United States

The Mendocino triple junction, where overlapping and interfingering southern Cascadia and northern San Andreas plate boundaries exist, is complicated, where oblique convergence and dextral shear interact. Northwest-striking, southwest-vergent thrust faults represent anelastic deformation related to Cascadia convergence while east-stepping Pacific-North America dextral shear generates strike-slip faults that may terminate in uplifted terranes with east-west striking reverse or thrust faults and folds or strike-slip faults that penetrate the Humboldt Bay region. The Russ fault, located immediately north of Cape Mendocino, is mapped as a north-vergent high angle reverse fault, however, we locate a topographic scarp along its strike that suggests a south-vergent reverse fault offsetting late Pleistocene to Holocene fluvial terraces. We conduct a Ground Penetrating Radar survey to explore subsurface evidence for faulting. Using regionally derived incision rates as a proxy for terrace age, topographic swath profiles provide scarp heights and a late Pleistocene slip rate of about 0.75 mm/yr.

Fluvial terrace mapping provides relative age control for geomorphic surfaces offset by the fault. This chronostratigraphic framework forms the basis for updated slip-rate calculations made for the scarp-forming fault. We use LiDAR-derived slope rasters to delineate terrace treads and calculate the relative elevation using a relative elevation model that represents the modern floodplain. Using the distribution of tread elevations, we correlate terraces along the lower Eel and lower Van Duzen rivers. Terraces north of the mouth of Van Duzen River display tectonic deformation in the form of a N20E striking syncline, while there is no apparent folding evident in terrace profiles to the south.
Using numerical ages from Bold (MS Thesis, 2022), a range of possible stratigraphic correlations of the terraces, and using a range of fault dips (30 to 60$\circ$), we calculate slip rates for the Russ fault that range from 1.5 to 6.0 mm/yr.

Keywords: Terrace Mapping, Active Faulting, Paleoseismology

*Speaker

Paleoseismological surveys for the identification of capable faults in urban areas: the case of the Mt. Marine Fault (Central Apennines, Italy).

Francesco Iezzi *† [1], Marco Francescone [2], Alberto Pizzi [2], Anna Maria Blumetti [3], Paolo Boncio [2], Pio Di Manna [3], Bruno Pace [2], Tommaso Piacentini [2,4], Felicia Papasodaro [3], Francesco Morelli [5], Marco Caciagli [4], Massimo Chiappini [4], Francesca D'ajello Caracciolo [4], Valerio Materni [4], Iacopo Nicolosi [4], Vincenzo Sapia [4], Stefano Urbini [4]

[1] University Federico II of Naples – Italy
[2] University G. D'Annunzio of Chieti-Pescara – Italy
[3] Istituto Superiore per la Protezione e la Ricerca Ambientale – Italy
[4] Istituto Nazionale di Geofisica e Vulcanologia – Italy
[5] University G. D'Annunzio of Chieti-Pescara – Italy

Paleoseismological investigations are key for constraining the geometry and the activity rates of capable faults in urban areas, especially when faults are highly segmented and their surface expression is altered by intense anthropic activity.
For the purpose of the mitigation of the fault displacement hazard associated with the Mt. Marine fault (Central Italy), we have performed two paleoseismological surveys within the town of Pizzoli (about 10 km NW of L'Aquila), where the fault is expressed with several splays arranged both along and across-strike. The surveys have been planned in order to explore (i) potential fault scarps altered by human activity, identified through fieldwork, LiDAR and aerial photographs analysis, and (ii) discontinuities in the stratigraphic record highlighted by geophysical investigations (ERT, GPR). The first survey (so-called Vallicella site) is characterised by a continuous trench about 156 m long and it intercepts two synthetic and one antithetic faults arranged across-strike. The three faults show evidences of multiple surface-rupturing seismic events, marked by colluvial wedges and infilled fractures, with observable coseismic displacement up to 80 cm. The second paleoseismological survey (so-called Collemusino site) is located about 720 m SE of the Vallicella site, and it is composed by two adjacent smaller trenches, with length about 20 m and 10 m each. The Collemusino site intercepts two faults also arranged across-strike, with both faults providing evidences of repeated surface-rupturing earthquakes.
Overall, the paleoseismological surveys on the Mt. Marine fault shows the occurrence of multiple surface-rupturing earthquakes on five different fault splays. The ongoing dating of key sedimentary units will allow us to constrain the age of the earthquakes, to relate the earthquakes observed on the different faults between themselves and with other published trenching data on the Mt. Marine fault, in order to understand how the fault activity is distributed within segmented faults.

*Speaker
†Corresponding author: francesco.iezzi@unina.it

Keywords: Earthquake geology, paleoseismology, Active faults.

Evidence of progradation of the reverse fault system of Quito towards a transpressive fault system

Alexandra Alvarado * [1], Laurence Audin * † [2], Léo Marconato [3], Nicolas Harrichhausen [3], Stéphane Baize [4], Hervé Jomard [5]

[1] Alexandra Alvarado – Ecuador
[2] Institut des sciences de la Terre (ISTerre) – OSUG, INSU, Université Joseph Fourier - Grenoble I, Université de Savoie, IFSTTAR, IRD, CNRS : UMR5275 – BP 53 38041 Grenoble cedex 9, France
[3] Institut des Sciences de la Terre – Institut National des Sciences de l'Univers, Institut de recherche pour le développement [IRD] : UR219, Université Grenoble Alpes, Université Gustave Eiffel, Centre National de la Recherche Scientifique : UMR5275, Université Savoie Mont Blanc – France
[4] Institut Radioprotection Sûreté Nucléaire (IRSN - BERSSIN) – Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – Fontenay-aux-Roses, France
[5] Institut de Radioprotection et de Sûreté Nucléaire – Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – France

In Quito region of Ecuador, the N–S striking Quito Fault System (QFS) extends over 60 km along the western Cordillera and the NE striking Guayllabamba Fault System (GFS) extends over 30 km through the Inter-Andean Depression. Hanging paleovalleys, deflected drainage networks, and captured canyons show these two large contemporaneous fault systems actively deforming Pleistocene volcanoclastic deposits. However, low deformation rates and thick volcanic cover have not allowed for in-depth studies of their geometry and kinematics. In particular, northeast of the reverse QFS, the strike-slip GFS aids the eastward transfer of regional stress and deformation toward the Chingual fault. Only one historical crustal earthquake, the 1587 Guayllabamba earthquake (6.4 MIc _˜Mw), is known to have occurred close to this structure. This event has been associated with either the QFS or the GFS, based on the spatial distribution of tremor intensities (Beauval et al., 2010), however, few witnesses and the great regional shaking intensity of this earthquake have prevented a reliable identification of the source fault. Recent seismic swarms now point to seismotectonic activity in the transfer zone between the Quito reverse system and the GFS transpressive fault system. Clustering around the new airport facilities, the strike slip motion in the GFS is represented in the focal mechanisms with a vertical geometry, consistent with a (right-lateral?) slip component.

Keywords: reverse fault, transpressive systems, seismicity

*Speaker
†Corresponding author: audin@ird.fr

Tectonic Transfer from the Western Alpine Front to the French Rhône Valley in its 3D-Structural Context

Christian Sue * [1], Andrea Walpersdorf [2], Dorian Bienveignant [2], Lina Al Najjar [2], Estelle Hannouz [2], Anne Lemoine [3], Stéphane Baize [4]

[1] University Grenoble Alpes, University Savoie Mont Blanc, CNRS, IRD, IFSTTAR, ISTerre, Grenoble – Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS, IRD, IFSTTAR, ISTerre, 38000 Grenoble, France – France
[2] University Grenoble Alpes, University Savoie Mont Blanc, CNRS, IRD, IFSTTAR, ISTerre, Grenoble – CNRS : UMR5275 – France
[3] BRGM – BRGM, F-45060 Orléans, France – France
[4] Institut Radioprotection Sûreté Nucléaire (IRSN - BERSSIN) – Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – Fontenay-aux-Roses, France

The Western Alps current tectonics is characterized by seismically active radial extension in the core of the belt, combined with transcurrent to transpressive tectonics in its external zone and foreland associated with a moderate seismicity. We focus on the tectonic transfer from the W-Alps to their foreland, namely the French Rhône Valley, a region with high societal challenges, including demography, nuclear powerplants, and chemical industries. We combine seismotectonic and geodetic (GNSS) approaches to constrain the stress and strain fields of the area extended from the alpine External Crystalline Massifs to the eastern edge of the French Massif Central, which encompasses the Rhône Valley. Seismic strain rates for a set of subareas defined on tectonic arguments (seismotectonic zoning) have been evaluated. They are processed by combining the total seismic energy obtained with statistical integrations of Gutenberg-Richter distributions with representative focal-mechanisms obtained from stress inversions. Seismic strain rates are then compared to the geodetic strain field obtained from an updated GNSS solution focused on the study area. Seismic strain rates of subareas in the Rhone Valley and surroundings range between a few nanostrains/yr and 10E-2 nanostrains/yr. In terms of amplitude, geodesy seems to provide deformation rates one order of magnitude higher than seismicity. However, our seismic strain tensors are globally consistent with the geodetic ones, specifically in the front of the Alps (Belledonne region), where seismic and geodetic networks are denser. In a last step, we replace these strain and stress fields in a new 3D-structural model, which has been developed on purpose. It integrates the main crustal units and the main faults of the area, allowing to better constrain the relationship between the current deformation and stress patterns of the Rhône Valley under the Alpine influence, and the inherited fault system carving the entire domain.

Keywords: Alps, Rhone Valley, active deformation, 3D structural modelk

*Speaker

Estimation of the slip rate along the un-ruptured fault segment of the M7.2 1896 Rikuu earthquake, northeast Japan.

Shreya Arora *† [1], Hisao Kondo [2], Hideki Kurosawa [3], Kouta Koshika [3]

[1] Bates College – United States
[2] Geological Survey of Japan – Japan
[3] OYO Corporation – Japan

The northeast Japan arc is one of the most seismically active plate boundary systems in the world recording a convergence rate of ~9 cm/yr between the Pacific and the Eurasian plates. The plate boundary has hosted several large magnitude earthquakes, including the 2011 Tohoku mega-subduction earthquake (Mw 9.0-9.1) and several intraplate earthquakes of which 1896 Rikuu earthquake (M7.2) is one the largest on-land reverse fault earthquakes in the history of Japan. The 1896 Rikuu earthquake ruptured the northern segment of Ou Backbone Range (OBR) along the Eastern Margin Fault Zone of Yokote Basin (EFZYB), while the southern segment remained un-ruptured. Despite the extensive paleoseismic investigations along the ruptured segment, the slip rate estimates, and the recurrence interval remained largely unresolved along the southern un-ruptured segment. Through this work, we report the long-term slip rate and recurrence interval along the Higashi Chokai san Fault and the signatures of active faulting along the Kanazawa and Omoriyama Faults. Based on the seismic reflection and borehole survey, we have estimated a vertical displacement of 29.3-36.1 m across the Higashi Chokai san Fault, a long-term slip rate of 1.6-1.9 mm/yr over the past 35 ka, and a recurrence interval of about 3800-4600 yr.

Keywords: 1896 Rikuu earthquake, Slip Rate, Recurrence Interval, Seismic Survey, Northeast Japan.

*Speaker
†Corresponding author: sarora@bates.edu

Analysis of trenching records in central Apennines: from data uncertainties to earthquake recurrence estimates and rupture scenarios

Francesca Romana Cinti * [1], Daniela Pantosti [2], Anna Maria Lombardi [2], Riccardo Civico [2]

[1] Istituto Nazionale di Geofisica e Vulcanologia - Sezione di Roma – Italy
[2] Istituto Nazionale di Geofisica e Vulcanologia - Sezione di Roma – Italy

Paleoseismology reconstructs histories of recurrent earthquakes back to pre-historical times. These reconstructions include uncertainties depending on the evidence used to recognize the paleoearthquake and particularly on the definition of its age. Moreover, because of possible hiatuses in the trench exposures, some events may be missed. The availability of more sites along a fault and the search for age correlations between events in different trenches, increases the possibility to compile a robust history of surface faulting earthquakes on the individual fault. On larger scale, this allows testing the contemporaneity of ruptures on multiple nearby faults, and defining the regional characteristics of earthquake recurrence and rupture scenarios. These are issues for developing earthquake hazard analysis in a specific region or for a specific fault based on a window of several millennia. We analyze the activity of the main active faults within Central Apennines through the existing paleoseismic data, with two main objectives: -definition of methods to encompass paleoseismic data, and -picture regional scenarios of faults activation within a given interval of time. We evaluate the uncertainties affecting the paleo-events and build a dataset differentiating for levels of robustness, and show that the 7 kyr time span-paleoearthquake data are the more adequate to be statistically processed and of use for building fault rupture scenarios and recognizing recurrence patterns. Then, through a quantitative multistep method, we integrate paleoseismic data from multiple sites into an individual fault earthquake history. The analysis of the paleoearthquake timelines of individual faults allowed us to evaluate the average regional IETs in the past 7 kyr, providing insight on the time spacing surface faulting events in the region, independently from which fault ruptured. We compare the values obtained using the compiled differentiated dataset and also with those based on different calculations and time-windows. The specific statistical analysis on the individual faults is underway.

Keywords: Paleoseismology, Regional earthquake recurrence, Surface rupture scenarios, Earthquake storms, Statistical modeling, Central Apennines

*Speaker

Structural architecture and kinematic properties of faults in the Dubrovnik area and its hinterland (Croatia, Bosnia and Herzegovina, Montenegro)

Josipa Maslač * [1], Bojan Matoš [2], Ivica Pavičić [3], Igor Vlahović [4]

[1] Croatian Geological Survey – Croatia
[2] Faculty of Mining, Geology and Petroleum Engineering – Croatia
[3] Faculty of Mining, Geology and Petroleum Engineering – Croatia
[4] Faculty of Mining, Geology and Petroleum Engineering – Croatia

The area of southern Dalmatia is considered one of the three tectonically most active regions in Croatia, characterized by moderate to strong seismicity, with several instrumentally recorded earthquakes of Mw≥6.Identification of potential seismogenic sources and their detailed segmentation within epicentral areas is of great importance in seismic hazard and risk assessment procedure.Hence, determination of the seismogenic potential of the mapped fault zones,i.e., seismogenic fault segments usually convey overlap of geological and seismological data. Initial dataset of five regional geological cross-sections (c.55 km long, perpendicular to the Dinaridic structures) based on 1:100,000 Basic Geological Map, were constructed and used for building a conceptual geological three-dimensional model of the study area.Input data were pre-processed using ArcGISPro, ArcGIS10.1 and AdobeIllustrator software, while conceptual three-dimensional model and assessment of modelled faults geometrical properties were made using Petroleum Expert Move software.Results of structural modelling with associated depths and faults geometrical relations as well as seismological data indicate fault-related fold structures that accommodated rock vertical displacement greater than 3500 m.Furthermore, faults geometrical peculiarities suggest complex tectonic history that is mainly associated with presence of Early Triassic ductile deposits representing decollement horizon.Distribution of hypocenters suggest complex seismogenic source geometries, with general subvertical orientation in the near surface whereas in the deeper sections hypocenters indicate listric-shaped geometry of seismogenic sources.Empirical computation of identified fault segments maximal magnitudes estimates potential Mw between 6.29-7.53. This initial structural model will be further improved combining additional geological profiles with the proposed model, adding detailed seismological data collected by the Croatian-Seismological-Survey as well as including available seismic reflection profiles recorded in the nearby Adriatic offshore. It is expected that using such an approach will contribute to detailed definition of local seismogenic sources,i.e., fault's segments in the wider Dubrovnik area, increasing overall knowledge on present seismogenic sources and potential geohazards in the area.

*Speaker

Keywords: Dinarides, Dubrovnik, nappe tectonics, 2D/3D structural modelling, ArcGIS, MOVE, seismogenic potential, seismicity, earthquake magnitude

Sites selection for creepmeter fault monitoring in a complex volcano-tectonic framework: the Mt. Etna eastern flank as an example

Giorgio Tringali * [1], Pia Victor [2], Raffaele Azzaro [3], Domenico Bella [4], Alessandro Bonforte [3], Silvia Crosetto [2], Gianluca Groppelli [5], Alessandro Michetti [1], Rosario Pettinato [4], Morelia Urlaub [6]

[1] Dipartimento di Scienza e Alta tecnologia, Università degli Studi dell'Insubria, Como – Italy
[2] GFZ-Potsdam – Germany
[3] Istituto Nazionale di Geofisica e Vulcanologia - Sezione di Catania – Italy
[4] Studio di Geologia Domenico Bella, Acireale – Italy
[5] CNR - Istituto di Geologia e Geoingegneria, sezione di Milano – Italy
[6] GEOMAR - Helmholtz Centre for Ocean Research [Kiel] – Germany

Mt. Etna is one of the most active volcanoes representing an exceptional natural laboratory for in-depth studies on volcano-tectonic processes. The volcano is well monitored by the INGV-OE seismic and geodetic network onshore given the high population density along its slopes, which have been affected not only by volcanic eruptions but also by damaging earthquakes. Seismicity is higher in the eastern slope which is also affected by slow gravitational sliding toward the sea with an active deformation also offshore. Flank instability is accommodated by fault systems characterized by seismic and aseismic segments with normal and strike-slip kinematics, and bounded to the N by the Pernicana Fault and to the S by the Tremestieri-Trecastagni-Aci Trezza Faults. The Trecastagni Fault is monitored by two extensometers held by INGV-OE, while offshore monitoring has been recently improved with five GEOMAR transponders along the Aci Trezza Fault offshore extension. Dyke intrusions on Etna can cause stress variations along faults triggering earthquakes and flank instability; moreover, fault creep events can follow or precede earthquakes. This pattern of interacting phenomena demonstrates how changes in the stress regime trigger seismic and aseismic transients on different faults and also causes eruptions probably related to significant extensional regime in the crust. Thus, it is important to improve the actual monitoring system with creepmeters providing time series of displacement across active faults with continuous and high-resolution measurements (1 μm). In this work we provide the first results of the geological and geophysical investigations in the Etna eastern flank and we present the methodology to characterize best suited sites, currently in progress, for future installation.

Keywords: fault monitoring creepmeter Mt. Etna creep earthquake

*Speaker

Geological, geomorphological, geophysical and paleoseismic exploration along the Palomares Fault (southeast Iberian Peninsula)

Júlia Molins Vigatà *† [1,2], Raquel Martín Banda [3], María Ortuño [1], Juan Miguel Insúa Arévalo [2], Hector Perea [2], Paula Herrero Barbero [2], Juan Alcalde [4], Ramon Carbonell [4], Julián García Mayordomo [3], Octavi Gómez-Novell [1,5], Eulàlia Masana [1]

[1] RISKNAT Group, GEOMODELS, Departament de Dinàmica de la Terra i de l'Oceà, Facultat de Ciències de la Terra, Universitat de Barcelona, 08028 Barcelona, Spain – Spain
[2] Dpto. de Geodinámica, Facultad de Ciencias Geológicas, Universidad Complutense de Madrid. 28040 Madrid, Spain – Spain
[3] Instituto Geológico y Minero de España, CSIC, 28760 Madrid, Spain – Spain
[4] Geosciencies Barcelona, CSIC, 08028 Barcelona, Spain – Spain
[5] DiSPUTer, Università degli Studi "Gabriele d'Annunzio" Chieti-Pescara, 66013 Chieti, Italy – Italy

The Eastern Betic Shear Zone (EBSZ) is a crustal-scale structure across the regions of Almería and Murcia and one of the most active tectonic systems in the Iberian Peninsula. This zone absorbs a great part of the shortening between the Iberian and the Nubian plates in the western Mediterranean under a transpressive regime. Classical paleoseismological studies have been successfully done all along the main active faults of the system, with the aim to assess the seismic potential of the area. These studies have provided essential information about the slip rates and the geometry of these faults, used in seismic hazard analysis. The Palomares Fault (PF) is part of this system, bounding the EBSZ through the east and linking the Carboneras Fault with the Carrascoy Fault. The PF has a very wide fault zone (1 to 5 km) with a mainly left-lateral displacement. Despite its clear geomorphological expression, scarce paleoseismological studies have been carried out, representing a major knowledge gap in the EBSZ. We introduce here an initial project aimed at acquiring new data, in order to define the seismogenic parameters of the PF. We include a first detailed geomorphological analysis of the area, with potential new trenching sites, and a description of an outcrop of the fault trace. We also present the location of new seismic profiles along a fault segment, which will provide information about its geometry in depth. These preliminary works will allow us to give a first approach of the fault traces and segmentation, as well as to suggest future studies in the area.

Keywords: Eastern Betic Shear Zone, Palomares Fault, active faults, geomorphology

*Speaker
†Corresponding author:

Geomorphological evidence of Quaternary activity in the Amarguillo Fault, a transtensional structure within the Alhama de Murcia Fault system (SE Spain)

Octavi Gómez-Novell * [1,2], María Ortuño [2], Julián García-Mayordomo [3], Juan Miguel Insua-Arévalo [4], José Jesús Martínez Díaz [4], Eulàlia Masana [2]

[1] DiSPUTer, Università degli Studi "Gabriele d'Annunzio" Chieti-Pescara, 66013 Chieti, Italy – Italy
[2] RISKNAT Research Group, Geomodels institute. Dpt. of Earth and Oceans Dynamics. Faculty of Earth Sciences, University of Barcelona, 08028 Barcelona, Spain – Spain
[3] Instituto Geológico y Minero de España (IGME), CSIC, 28760 Madrid, Spain – Spain
[4] Departamento de Geodinámica, Facultad de Ciencias Geológicas, Universidad Complutense de Madrid, 28040 Madrid, Spain – Spain

The Alhama de Murcia Fault (AMF) is one of the most active structures in SE Spain, dominated by left-lateral transpression related to the current convergence between Africa and Eurasia. The AMF presents many geomorphological and paleoseismic evidence of activity during the Quaternary, especially in its central and SW sections (Góñar-Lorca and Lorca-Totana) where most of the paleoseismic research has focused. Contrarily, to the NE in the Totana-Alhama section, such deformation is diffuse and distributed over a wide 3-4 km transect, making the development of detailed geomorphological and paleoseismic studies more difficult. Here we present a morphotectonic analysis in a unique sector of the Totana-Alhama section where the AMF ramifies into the Amarguillo Fault (AF), one of its most geomorphologically prominent structures. The AF extends NNE-SSW for _˜11 km and is composed by at least five subparallel fault strands displaying a small horst and graben-like structure with left-lateral component. Contrasting with the general kinematics of the AMF, the AF is interpreted as a transtensional bend within the regional _˜N150º shortening vector. The Quaternary activity of the AF is demonstrated by the presence of faulted alluvial fan deposits of Middle to Late Pleistocene age, as well as by geomorphological features such as fault scarps, lineations and drainage channel deflections. In the central sector, near the Campis creek, the morphological expression of the AF is the clearest out of the whole Totana-Alhama section, suggesting that the AF could be absorbing an important part of the slip in the segment. Our observations highlight the importance of performing paleoseismic investigations in the AF to constrain its paleoseismic parameters for seismic hazard assessment. Consequently, we also propose a suitable site with potentially affected young sediments for the development of future paleoseismic trenching studies.

*Speaker

Keywords: Amarguillo Fault, Alhama de Murcia Fault, morphotectonic analysis, geomorphology, paleoseismology

Quantifying the slip over various time scales on active normal faults in the Apennines (Italy): challenges on the Liri fault from paleoearthquakes to long-term slip rate

Magali Riesner * [1], Lucilla Benedetti [2], Stéphane Baize [3], Matthieu Ferry [4], Jules Fleury [5], Stefano Pucci [6], Stéphanie Gautier [7], Stephane Mazzotti [8], Fabio Villani [6], Hervé Jomard [9]

[1] Centre européen de recherche et dénseignement des géosciences de lénvironnement – Institut de Recherche pour le Développement : UMR$_D161, AixMarseilleUniversité : UM34, CollègedeFrance : UMR7330, InstitutNationaldesSciencesdel'Univers, CentreNationaldelaRechercheScientifique : UMR7330, InstitutNationaldeRecherchepourl'Agriculture, l'Alimentationetl'Environnement : UMR1410 - -France$

[2] Centre européen de recherche et d'enseignement de géosciences de l'environnement (CEREGE) – Aix Marseille Université, INSU, Institut de recherche pour le développement [IRD], CNRS : UMR7330 – Europôle Méditerranéen de l'Arbois - Avenue Louis Philibert - BP 80 - 13545 Aix-en-Provence cedex 4, France

[3] Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – BP17 92262 Fontenay-aux-Roses Cedex, France

[4] Géosciences Montpellier – Institut National des Sciences de l'Univers : UMR5243, Université de Montpellier, Centre National de la Recherche Scientifique : UMR5243, Université des Antilles – France

[5] Centre européen de recherche et dénseignement des géosciences de lénvironnement (CEREGE) – Aix Marseille Université : UM34, Collège de France : UMR7330, Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement, Institut de Recherche pour le Développement : UMR$_D161, CentreNationaldelaRechercheScientifique : UMR7330, InstitutNationaldesSciencesdel'Univers - -EuropôleMéditerranéendelÁrbois - AvenueLouisPhilibert - BP80 - 13545Aix - en - Provencecedex4, France$

[6] Istituto Nazionale di Geofisica e Vulcanologia - Sezione di Roma 1 – Italy

[7] Géosciences Montpellier – Université de Montpellier : UMR5243, Centre National de la Recherche Scientifique : UMR5243 – Place Eugène Bataillon - 34095 Montpellier cedex 5, France

[8] Géosciences Montpellier – Université Montpellier II - Sciences et Techniques du Languedoc – France

[9] Institut de Radioprotection et de Sûreté Nucléaire – Institut de Radioprotection et de Sûreté Nucléaire (IRSN), 92262 Fontenay-aux-Roses cedex, France – France

Long-term fault escarpments are built by the accumulation of individual earthquakes releasing crustal tectonic loading. A better knowledge of co-seismic rupture extents and spatiotemporal slip variability along active faults is essential for seismic hazard assessment.
Up to now, studies focused on a short timeframe, over few seismic cycles, making it difficult to apprehend the cumulative slip distribution. Here, we aim at quantifying the slip variability over several timescales ranging from a few months to a few million years on a fault system.
Our study focusses on the _˜50 km-long Liri fault, SW of the Fucino basin. Detailed mapping of the fault trace on high-resolution Digital Elevation Model from UAV-acquired images, Pleiades

*Speaker

images and Lidar together with field observations revealed a variation in the morphological expression of the fault. To the north, the faut trace is _˜16 km-long located on the eastern side of _˜2km-wide limestone ridge, reaching _˜1300m elevation. Two bends in the fault trace, made of _˜5km long segments, can be observed with the fault strike varying between N115◦ and N140◦. There, no Quaternary deposits can be observed on the hanging wall. In the 30 km-long southern section, the cumulative escarpment composed of numerous splays is evidenced by a sharp trace, offsetting morphological surfaces. It is located on the eastern side of a relief reaching 1700m elevation. Three major bends are observed in this fault section, separating 10-30 km-long segments striking between N110◦ and N160◦. We excavated a small trench at the base of the escarpment within the Quaternary deposits affected by the fault. We sampled for cosmogenic exposure dating an alluvial surface composed of unconsolidated fanglomerates which appears offset by 5-10m of cumulative displacement. We aim at constraining both the recent fault activity, its slip-rate and associated past earthquakes, and quantifying how the displacement varies along the fault.

Keywords: long, term slip rate

Studying seismic supercycles through coral microatolls: the study case of Ishigaki island, Japan.

Sophie Debaecker *† [1], Kenji Satake [1], Nathalie Feuillet [2], Kohki Sowa [3], Masaki Yamada [4], Tetsuro Sato [1], Mamoru Nakamura [5], Chuan-Chou Shen [6], Tsai-Luen Yu [6], Atsushi Watanabe [1], Ayaka Saiki [1], Jean-Marie Saurel [2], Giovanni Occhipinti [2]

[1] Earthquake Research Institute [Tokyo] – Japan
[2] Institut de Physique du Globe de Paris – Université de Paris – France
[3] Kikai institute for coral reef sciences – Japan
[4] Shinshu University [Nagano] – Japan
[5] University of the Ryukyus [Okinawa] – Japan
[6] National Taïwan University – Taiwan

The Ryukyu islands belong to the curved Ryukyu subduction zone, between Japan main island and Taiwan. Along the megathrust, no significant earthquake has been documented in at least the past 250 years. Debate are therefore ongoing on whether the megathrust is aseismic and steadily creeping, or if this subduction zone has already hosted large earthquakes and has been loading strain ever since. In this work, we aim to improve our understanding of subduction zone behavior. We propose to review and extend the earthquake catalog through the analysis of coral microatolls.
In Ishigaki island, we documented plenty of fossil coral microatolls in Nagura site. Coral microatolls are paleo-geodetic markers of the relative past sea-level. They can record vertical motions with precision of centimeters. Through different fieldtrips between 2018 and 2021, we sliced and analyzed up to five corals with age ranking between 2 to 4.5 ka. Their intern stratigraphy revealed different events of the past relative sea-level. Some of them are sudden and pluridecimetric, and can be linked to earthquakes. We discuss the origin of the different events, and we use elastic modelling to test the influence of megathrust processes in the signal we documented.

Our results tend to draw patterns of seismic supercycles, with periods of frequent subduction earthquakes of magnitude of class 7 to 9, and periods of quiescence. Using correlation with traces of past tsunamis in the region, we suggest that some of these past earthquakes could have ruptured to the surface and generated tsunamis.

Keywords: Coral microatolls, seismic supercycles, megathrust earthquakes

*Speaker
†Corresponding author: debaecker.sophie@gmail.com

Trenching the Greater Caucasus Frontal Thrusts

Ian Pierce * [1], Sabina Kazimova [2], Ben Johnson [1], Neill Marshall [1], Richard Walker [1]

[1] University of Oxford – United Kingdom
[2] Republican Seismic Survey Center – Azerbaijan

Here we present the results of the first paleoseismic investigation of the Greater Caucasus Frontal Thrust in Azerbaijan. The Greater Caucasus Thrust is an imbricate fold and thrust belt extending nearly 900 km from the Caspian Sea to the Black Sea. In Azerbaijan, this frontal belt is the most active part of the subduction zone, and both GPS and structural geologic data show that it accommodates nearly 10 mm/yr of north-directed crustal shortening between Eurasia and the Iranian plate. Azerbaijan has experienced numerous historical devestating earthquakes, including estimated _˜M6.9-7 events in 1667 and 1902 that destroyed the historical capital city of Shemakhi. To this day, the causative faults and surface ruptures of these events remain unknown. A spring 2022 field campaign produced a single 5-m-deep trench across a 1.5-m-high fault scarp in a small alluvial valley near Agsu, Azerbaijan, less than 20 km from Shemakhi. A faulted colluvial wedge deposit, and faulted and folded sediments provide clear evidence of at least two paleoseismic events, with a combined dip slip displacement of > 6 m along a _˜20○ north-dipping thrust fault. Radiocarbon dating of shells and charcoal recoverd from these sediments will provide limits on the timing of these earthquakes. These results provide a first step towards building a paleoseismic history of the many faults of Azerbaijan, improving regional seismic hazard models, and towards understanding the tectonics of the Greater Caucasus.

Keywords: historical earthquakes, paleoseismology, caucasus

*Speaker

Paleoseismology of the Sagaing Fault near Mandalay, Myanmar

Ray Weldon * [1], Yu Wang [2], Xuhua Shi [3], Saw Ngwe Khaing [4], Soe Min [5], Weerachat Wiwegwin [6], Elise (lili) Weldon [1], Timothy Dawson [7], Myo Thant [5], Lin Thu Aung [8], Aron Meltzner [8], Eric Lindsey [8], Kyle Bradley [8]

[1] University of Oregon – United States
[2] NTU – Taiwan
[3] ZJU – China
[4] Hinthada university – Myanmar (Burma)
[5] Myanmar Earthquake Committee – Myanmar (Burma)
[6] DMR – Thailand
[7] CGS – United States
[8] NTU – Singapore

In the context of a series of SE Asian field training courses (2016-2019) we excavated 12 paleoseismic trenches and cleared and progressively cut back several natural exposures across the Sagaing Fault 10 km NW of Mandalay, Myanmar. A step-over between the villages of Yae Khar and Yuan Da Yah provide uphill-facing scarps that trap rapidly accumulating, well-layered late Holocene and historic sediments that preserve multiple earthquake surface ruptures, dateable organic material and cultural artifacts. While ground water had to be pumped in some trenches and reworked charcoal from the older, rising hangingwall of the active fault zone complicates C-14 dating, at least 4 surface ruptures that occurred during the past _˜1000 years have been identified in multiple exposures and many older events could be characterized and dated with additional work. Individual events are identified on multiple traces of faults with vertical separations of 10s of cms, terminating upward at consistent stratigraphic levels associated with weakly-developed soils. Unit thicknesses and facies contrasts across faults, limited 3d excavation, isopachs spanning adjacent trenches and surface geomorphology (mapped with ground-based LiDAR and drone imagery) suggest multi-meter, largely lateral offsets.

Keywords: paleoseismology, Sagaing Fault, Mandalay, Myanmar, Field Training Course

*Speaker

Late Cenozoic reactivation of trench – parallel strike – slip system and tectonic forcing of drainages close to the Oroclinal Bend, Andean forearc of N-Chile

Ambrosio Vega Ruiz * [1], Pia Victor [1], Vanessa Steinritz [2], Ariane Binnie [3], Gabriel Gonzalez [4,5], Kathrin Lampert [6], Klaus Reicherter [2], Steven Binnie [3]

[1] Deutsches GeoForschungsZentrum GFZ – Germany
[2] Neotectonics and Natural Hazards, RWTH Aachen University – Germany
[3] Institute of Geology and Mineralogy, University of Cologne – Germany
[4] Centro de Investigación para la Gestión Integrada del Riesgo de Desastres (CIGIDEN) – Chile
[5] Departamento de Ciencias Geológicas, Universidad Católica del Norte – Chile
[6] Institute of Zoology, University of Cologne – Germany

Translator

The Western Flank of the Altiplano in northernmost Chile presents important latitudinal changes in its geomorphologic and tectonic expression along the forearc: In the north (_˜18○45'-19○30'S), the forearc is strongly dissected by exoreic drainages. Main structures in the Coastal Cordillera are _˜40-50 km length NE-SW transtensional(?) faults whereas in the Precordillera _˜50-60 km length thrust faults have a NW-SE strike. South of _˜19○30', drainages are low incised and their baselevel is located at _˜1000 m.a.s.l, within the Pampa de Tamarugal basin. Main structures in the Coastal Cordillera are _˜20-30 km length W-E reverse faults and the Precordillera thrust faults have a NNW-SSE strike.

The thick Neogene infill of the Longitudinal Valley is a challenge for classical remote and field structural mapping, as it masks fault activity. However, preservation of widespread perturbed fluvial landforms and the almost no-existent surface coverage due to long-term hyperaridity of the Atacama Desert set an optimal scenario to unravel the so far not well understood tectonic evolution of this area.
An exhaustive fault mapping based on high resolution DEMs, satellite and UAV imagery data was combined with the analysis of orientation and patterns of low incised windgaps, and longitudinal profiles of major rivers. A compilation of cosmogenic exposure ages of paleosurfaces (Evenstar et al., 2017) was used for interpretation of the incremental tectonic evolution. This led to detailed evidence, suggesting Late Cenozoic transpressive reactivation of a Mesozoic inherited trench-parallel strike-slip fault zone for _˜110 km along a strike of NW-SE in the present Longitudinal Valley. Allocation of major rivers towards the faults tips, rotation and disconnection of

*Speaker

low incised drainages are direct consequence of the reactivation of this fault system. We suggest that the active fault system plays a complementary roll in the development of exoreic-endoreic drainages in this complex sector of the Andean forearc.

Keywords: Strike, slip, Orocline bend, tectonic forcing, drainages, lowlands

First palaeoseismological constraints on the Anghiari normal fault (Upper Tiber Valley, Northern Apennines)

Alessio Testa * [1], Paolo Boncio [1], Stéphane Baize [2], Francesco Mirabella [3], Stefano Pucci [4], Cristina Pauselli [3], Maurizio Ercoli [3], Magali Riesner [5], Bruno Pace [1], Lucilla Benedetti [6]

[1] University G. D'Annunzio of Chieti-Pescara – Italy
[2] Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – BP17 92262 Fontenay-aux-Roses Cedex, France
[3] Department of Physics and Geology [Perugia] – Italy
[4] Istituto Nazionale di Geofisica e Vulcanologia - Sezione di Roma 1 – Italy
[5] Centre européen de recherche et dénseignement des géosciences de lénvironnement – Institut de Recherche pour le Développement : UMR$_D161, AixMarseilleUniversité : UM34, CollègedeFrance : UMR7330, InstitutNationaldesSciencesdel'Univers, CentreNationaldelaRechercheScientifique : UMR7330, InstitutNationaldeRecherchepourl'Agriculture, l'Alimentationetl'Environnement : UMR1410 - -France$
[6] Centre européen de recherche et d'enseignement de géosciences de l'environnement (CEREGE) – Aix Marseille Université, INSU, Institut de recherche pour le développement [IRD], CNRS : UMR7330 – Europôle Méditerranéen de l'Arbois - Avenue Louis Philibert - BP 80 - 13545 Aix-en-Provence cedex 4, France

The Upper Tiber Valley is one of the fluvio-lacustrine basins of the northern Apennines resulting from the extensional processes which have affected this sector of the chain since late Pliocene. Extension in the Northern Apennines is accommodated by a low-angle east-dipping detachment, known in literature as the Altotiberina Fault. The seismogenic potential and the seismic behaviour of this low angle normal fault are still debated. The Anghiari fault is a 11 km-long segmented NE-dipping normal fault bounding the western side of the Upper Tiber Valley and belonging to the Altotiberina low-angle normal fault system. Here, we provide unprecedented evidence of the Holocene activity of the Anghiari fault through geological, geophysical and palaeoseismological investigations.

The Anghiari fault is composed of at least two nearly parallel splays. One splay runs at the base of the Pleistocene Anghiari ridge, juxtaposing the late Quaternary alluvial deposits of the Tiber Valley against Middle Pleistocene continental deposits. The other splay is located within the Middle Pleistocene units of the Anghiari ridge.
Detailed geomorphological analysis, geological mapping and near-surface geophysics on this latter splay enabled us to select two sites for palaeoseismological trenching. Radiocarbon dating of faulted sediments provides constraints for late Holocene and historical surface faulting events significantly contributing to the estimation of the seismic hazard in the region.

*Speaker

Keywords: Palaeoseismology, normal fault, seismic hazard

Paleoseismological investigation in a remote region of Kalimantan, Indonesia

Astyka Pamumpuni * [1,2], Dee Ninis [3], Naomi Maria Neysa Prayacita [1]

[1] Institut Teknologi Bandung – Indonesia
[2] Center for Earthquake Science and Technology ITB – Indonesia
[3] Seismology Research Centre Australia – Australia

We undertook a paleoseismological investigation of a fault in a remote region of Kalimantan, Indonesia, to determine whether the fault should be considered active (i.e., having ruptured in the last 11 ka) for a nearby site-specific PSHA. Our study relied on National *Seamless Digital Elevation Model* (DEMNAS) and LiDaR-derived elevation data to delineate the fault, which delineated the structure with a total length of _˜60 km and is thereby capable of hosting an earthquake of _˜Mmax7.1. In the field, resistivity surveying at two sites identified planes which coincided with the approximate location of the fault strands as interpreted from the LiDaR data. Trenching at both of these sites – which, due to the remote nature, had to be undertaken manually - exposed un-faulted alluvial deposits. Samples of organic matter collected from these un-faulted sediments yielded ages of between 1669 cal AD and 3960 cal BC at one site and 1151-1206 cal AD from the second site, suggesting that the fault has not produced a ground-rupturing earthquake in the last _˜834-732 years; these young sediment ages are not surprising in such a humid environment. Because of the obvious surface expression of the fault in LiDaR imagery, we suspect this structure may have ruptured within the last 11 ka, and may therefore be active, albeit with a relatively low slip rate. Based on previously identified active faults in Kalimantan whose morphological expression appears similar, we have inferred a slip rate for this fault of 0.3-0.5 mm/yr.

Keywords: paleoseismology, Kalimantan, Indonesia

*Speaker

Stress field changes in Central Europe since Late Miocene to date as determined from volcanic rocks and extensometric measurements in the Bohemian Massif, Central Europe

Jakub Stemberk *† [1], Miroslav Coubal [1,2], Josef Stemberk [1], Petra Štepančíková [1]

[1] Institute of Rock Structure and Mechanics, The Czech Academy of Sciences, V Holešovičkách 94/41, Prague 8, 18000, Czech Republic – Czech Republic

[2] Institute of Geology, The Czech Academy of Sciences, Rozvojová 269, Prague 6, 16000, Czech Republic – Czech Republic

The presentation will show the results of the stress field reconstruction in area of the Rychlebské hory Mts. (Bohemian Massif, Central Europe) during period since Late Miocene to date and its implication to the fault kinematics and dynamics. The classical methods of paleostress were used and applicated on stria on slickensides datasets measured in the dated volcanic rocks and on present-day observed 3D fault movement dataset measured by extensometers - the TM-71 gauges. The results show switching of tectonic phases with dominant compression, transtension or extension. Each stress regime is characterized by the orientation of the principal parameters. Six different paleostress field regimes from the Late Miocene to Quaternary and three different to-date stress field regimes were distinguished. The timing of the derived regimes was determined more accurately in comparison with classical geological approach and is in good accordance with the data reported from different regions in western and northern European Alpine Foreland, which suggests their broader validity. The to-date stress field behaviour is characterized as non-linear, short-periodical switching of two compressional stress/strain states – WNW-ESE to NW-SE compression corresponding to the stress field of the Western European stress domain and NNE-SSW corresponding to the stress field of the NW part of the Carpathian stress domain. The extensional state, oriented NW-SE, corresponding to gravitational spreading due to the Rychlebské hory Mts. Quaternary uplift, was recognised. Moreover, the orientation of theoretical planes with maximum shear stress and with a high tendency to dilate for all individual (paleo)stress regimes were defined and compared with the orientation of known faults within the broader region suggesting their activity and kinematics.

Keywords: stress field canages, paleostress analysis, extenzometric measurment, Bohemian Massif, Central Europe

*Speaker

†Corresponding author: jakub.stemberk@irsm.cas.cz

Architecture, upper crustal extension, and collapse of a continental shelf raised at an accelerated rate during the Quaternary, northern Chile

José Gonzalez-Alfaro *† [1], Et Al. [2]

[1] Universidad de Chile – Chile
[2] N/A – Chile

The coastal forearc of the Central Andes is characterized by the presence of quaternary crustal faults which have contributed to the landscape evolution. The relationship between these structures and the subduction processes is currently under discussion. In this work, we propose that normal faults located in the upper continental margin act mainly as structures reactivated by crustal uplift, which has been accelerated from the Middle Pleistocene to the Holocene in Mejillones Peninsula, northern Chile. We obtained both surface positioning through differential GPS campaigns and submarine seismic profiles data, and we performed digital elevation models to carry out a morphometric analysis of the escarpment and hanging wall block of the Mejillones Fault, which has a scissor-like geometry and submarine normal fault segments that offset the continental shelf seabed. The Mejillones Fault System (MFS) stretches across the seafloor about 30 km, affecting seismic-stratigraphic units interpreted as Neogene-Quaternary deposits with brittle and ductile deformation, and the presence of morphotectonic features corresponding to horst and hemigraben tectonic blocks. In the northern tip point of the MFS, we observed a transition zone with different structural styles and an overlapping characterized by submarine mega-landslides and fault scarps with accumulated vertical offsets of 300-400 m height, along the continental shelf break slope. The activity of these faults is evidenced by an acceleration in their slip rates during the Quaternary. We conclude that these normal faults play a key role in the geomorphological construction of the coastal relief, being structures that accommodate the upper crustal extension which is a manifestation of shortening occurring at the base of the continental crust and tectonic underplating possibly due to changes in the physical properties of the plate contact. Thus, coastal geomorphology would be a useful geological discipline to evidence indirectly the processes that occur several kilometers deep in active continental margins.

Keywords: tectonics, active margin, Chile

*Speaker
†Corresponding author:

Quaternary mapping and paleoseismic trenching of the Bonham Ranch fault: An active structure along the Walker Lane/Basin and Range transition zone, Nevada USA

Rich Koehler *† [1]

[1] University of Nevada – United States

The Bonham Ranch fault is an east-dipping normal fault which accommodates extensional deformation along the boundary between the Walker Lane and Basin and Range tectonic provinces in western Nevada USA. At this latitude, approximately 5-7 mm/yr of dextral shear is accommodated across the northern Walker Lane and a small amount of shear and extension is partitioned to faults in the western Basin and Range. The Bonham Ranch fault splays off the northwest trending Pyramid Lake fault (a major strike-slip fault of the Walker Lane) and extends north from the Terrace Hills to the Buffalo Hills along the western margin of Smoke Creek desert. The fault displaces latest Pleistocene and Holocene lacustrine and alluvial fan deposits, however paleoseismic information on the timing, recurrence, and slip rate have not been developed. Here I utilize recently acquired lidar data and field observations and present Quaternary surficial geologic mapping and scarp profiles along the Bonham Ranch fault. The results indicate that the fault displaces lacustrine deposits related to multiple pluvial lake cycles including the latest Pleistocene Lake Lahontan (_˜13.5 ka) and Younger Dryas (_˜12 ka), and the mid-Holocene Neopluvial (∼4,800–3,400 cal yr BP) lakes. The scarps range in height from 3 to 6 meters and are typically beveled with over steepened bases suggesting the occurrence of at least two earthquakes that postdate these deposits. The mapping results, combined with information from a paleoseismic trenching study (planned for May 2022) will serve to better characterize the timing and recurrence of earthquakes. Several tephra deposits exposed in stream cuts in faulted deposits will provide additional age control. The information will be applicable to assessing regional seismic hazards and contribute towards a better understanding of the style and rate of strain accommodation across the Walker Lane/Basin and Range transition zone.

Keywords: paleoseismicity, Walker Lane, Western USA

*Speaker
†Corresponding author: rkoehler@unr.edu

Impact of geometrical complexity on start and propagation of strike-slip earthquakes: The case of the 2021 Mw7.4 Madoi earthquake, China

Longfei Han Et Al. *† [1]

[1] Tianjin University – China

Initiation, development, and termination of strike-slip earthquakes are often related to fault geometrical complexity. Such complexity could also affect the surface rupture distribution and coseismic slip variation. Previous studies mostly focused on how earthquake ruptures stop due to these geometrical complexities, rather than how they start. We show that in fact many earthquake ruptures initiate in geometrical complexities, including the 2021 Mw7.4 Madoi earthquake that started in an extensional step-over with complex fault intersection. This earthquake propagated bilaterally along a 158-km-long surface rupture. Detailed mapping and classification of surface ruptures based on high-resolution UAV images provide a rare opportunity to analyze fault geometries and near-field effects of the Mw7.4 Madoi earthquake in the interior of the Qinghai-Tibetan Plateau. Optical correlation of satellite images provides both the parallel and the perpendicular component of the horizontal co-seismic slip for the central Madoi earthquake rupture. Combined with field investigation, our results show that the left-lateral horizontal coseismic displacements derived from field measurements is typically $\leq$0.6 m, in fact much lower than the displacements of 1–2.7 m measured from optical correlation; Such discrepancy indicates a large ratio of off-fault deformation along the central Madoi earthquake rupture. The initial decrease followed by rapid increase of the left-lateral coseismic slip west of the epicenter suggest that the epicentral geometrical complexity acts directly on the onset of the earthquake propagation; This obvious slow growth of the coseismic slip and rupture velocity in the initial propagation westward compared to the eastward branch suggests that the Madoi earthquake rupture started from the north-eastern boundary of the step-over and only later jumped across it propagate westward.

Keywords: geometrical complexity, earthquake propagation, strike, slip

*Speaker
†Corresponding author: hanlongfei_2019@tju.edu.cn

Paleoseismology along the Aksay segment of the Altyn Tagh Fault, China

Nicolas Pinzon *† [1], Yann Klinger [1]

[1] Institut de Physique du Globe de Paris – Institut National des Sciences de l'Univers, IPG PARIS, Université de la Réunion, Centre National de la Recherche Scientifique : UMR7154, Université Paris Cité : UMR7154 – France

The understanding of the seismicity distribution along multiple seismic cycles in major strike-slip fault systems relies on our knowledge of past seismic history. In this study, we used three trench excavations along the Aksai segment of the Altyn Tagh Fault to document preserved evidence of ground disruption in the sedimentological record such as vertical offset, fault cracks, and folding. Based on these indicators we reported nine paleo-earthquakes and six of these with a high probability of rupturing through the Aksai segment. Based on a Bayesian approach we present 95-percentile range ages of 6339 – 5220 BC, 5296 – 4563 BC, 3026 – 2677 BC, 1324 – 808 BC, 314 – 632 AD, and 916 – 1236 AD. The mean recurrence time is 1371±625yr with a COV of _˜0.46 suggesting a quasi-periodic behavior. The penultimate and antepenultimate events appear to correlate across the Aksai and Annanba segment (_˜200 km), furthermore the oldest earthquake is a strong candidate for a single large earthquake rupture that may have break through Aksai, Annanba and Xorxoli segment (roughly rupture longitude [3] 350 km). Variations in the COVs along the northern Altyn Tagh Fault accounts for the important control of local structural complexity and/or slip rate variations on the rupture behavior of major fault systems.

Keywords: paleoseismology, Altyn Tagh Fault, China

*Speaker

†Corresponding author: nipinzonma@unal.edu.co

Earthquakes of plate interiors

Paleoearthquakes Constrained by 2D and 3D Paleoseismic trenching: A case study along the Yangsan Fault, South Korea

Sambit Prasanajit Naik * [1], Thomas Rockwell [2], Su-Ho Jeong [3], Hyeon-Cho Shin [3], Young-Seog Kim [3]

[1] Pukyong National University – South Korea
[2] San Diego State University – United States
[3] Pukyong National University – South Korea

The Yangsan Fault is the most-longest (_˜200 km) right-lateral strike-slip fault crossing the south eastern Korean Peninsula which has the capability of generating large earthquakes. However, the paleoseismic information on slip rate, slip per event or the timing of past surface ruptures remains sparse along this fault. To explore these parameters along the Yangsan fault, we have excavated trenches across the central segment of the Yangsan fault. The exposed trench section shows at least five surfaces rupturing earthquakes preserved in the fluvial deposits. Luminescence and radiocarbon age dating of displaced units suggest the fault have generated at least five paleoearthquakes in the past. The most recent event(s) occurred during or slightly after the 6th to 8th century CE. The most recent earthquake is associated with 4.5m to 5.3m of lateral displacement of a paleochannel, based on 3-dimensional trenching. This magnitude of lateral displacement suggests an earthquake of at least Mw 7, which is the 1st ever evidence of large magnitude earthquakes along the Yangsan fault. The penultimate event occurred after 17 ± 1 ka ago and probably between 6.8 and 10.4 ka, whereas a third late Quaternary event occurred between the late Pleistocene/Holocene deposits. The oldest observed ruptures are preserved below an unconformity that probably dates to the last interglacial. An unknown number of ruptures may have occurred between the unconformity and the latest Pleistocene to Holocene period of erosion and sedimentation. This observation may indicate a clustered behavior of large earthquakes for the Yangsan fault with a recurrence interval in the range of 104 years. This long-term earthquake behavior along the Yangsan Fault may contribute to a better seismic hazard assessment in the SE Korean Peninsula.

Keywords: Yangsan Fault, Holocene Rupture, Paleoearthquakes, Earthquake Cluster, Seismic Hazard

*Speaker

New perspectives in studying active faults in metropolitan France

Stéphane Baize *† [1], Jean-François Ritz [2], Laurence Audin [3], Resif-Ats Fact Group [4]

[1] Institut de Radioprotection et de Sûreté Nucléaire – Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – France
[2] Géosciences Montpellier – Institut National des Sciences de l'Univers : UMR5243, Université de Montpellier, Centre National de la Recherche Scientifique : UMR5243, Université des Antilles – France
[3] Institut des Sciences de la Terre – Institut National des Sciences de l'Univers, Institut de recherche pour le développement [IRD] : UR219, Université Grenoble Alpes, Université Gustave Eiffel, Centre National de la Recherche Scientifique : UMR5275, Université Savoie Mont Blanc – France
[4] RESIF – Ministère de la Recherche et de l'Enseignement Supérieur, Ministère de la Transition écologique et solidaire – France

Mainland France is part of a plate interior with a strong structural heritage, undergoing a low rate of deformation, where destructive earthquakes can nevertheless occur. In this contribution, we emphasize that the knowledge of active faults is still largely fragmentary, and that significant efforts are needed to generate robust data, in particular on the numerous faults that still lack any study. This is the aim of the "Failles ACTives France" (FACT) axis launched in the framework of the Transverse Seismicity Action (ATS) of the Resif-Epos consortium.
We present some recent results, acquired by the members of the FACT axis along suspected active faults, and their potential follow-up investigations including new approaches and new tools to allow characterizing their Quaternary activity. The targeted faults are in mountainous areas, their forelands and in remote lowlands.
This contribution is developed in a Comptes-rendus Géoscience paper (Ritz et al., 2021).

Keywords: Mainland France, Active fault, Paleoseismogy, Earthquake geology, Plate interior

*Speaker
†Corresponding author: Stephane.BAIZE@irsn.fr

Paleoseismological investigations of the La Rouvière fault, unexpected source of the 11-11-2019, Mw4.9 Le Teil surface rupturing earthquake (Cévennes fault system, France)

Jean-François Ritz * [1], Stéphane Baize [2], Nicolas Cathelin [1,3], Camille Thomasset [1,4], Magali Riesner [5,6], Estelle Hannouz [7], Matthieu Ferry [1], Christophe Larroque [8,9], Laurence Audin [10], Laurent Bollinger [5], Kévin Manchuel [11], Christian Sue [7], Magali Rizza [6], Hervé Jomard [12], Pierre Arroucau [11], Romain Le Roux-Mallouf [11]

[1] Géosciences Montpellier – Institut National des Sciences de l'Univers : UMR5243, Université de Montpellier, Centre National de la Recherche Scientifique : UMR5243, Université des Antilles – France
[2] Institut de Radioprotection et de Sûreté Nucléaire – Institut de Radioprotection et de Sûreté Nucléaire, Institut de Radioprotection et de Sûreté Nucléaire, – France
[3] Institut de Radioprotection et de Sûreté Nucléaire – Institut de Radioprotection et de Sûreté Nucléaire – France
[4] EDF – EDF – DIPNN - CEIDRE - TEGG - SGG – France
[5] CEA – Commissariat à l'Énergie Atomique - CEA Bruyères-le-Châtel (Laboratoire de Détection et de Géophysique LDG) – France
[6] Centre européen de recherche et dénseignement des géosciences de lénvironnement – Institut de Recherche pour le Développement : UMR$_D$161, $AixMarseilleUniversité : UM34, CollègedeFrance : UMR7330, InstitutNationaldesSciencesdel'Univers, CentreNationaldelaRechercheScientifique : UMR7330, InstitutNationaldeRecherchepourl'Agriculture, l'Alimentationetl'Environnement : UMR1410 - -France$
[7] ISTerre – Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS, IRD, IFSTTAR, ISTerre, 38000 Grenoble, France – France
[8] Laboratoire Géoazur – Université Côte d'Azur, CNRS, Observatoire de la Côte d'Azur, IRD, Sophia Antipolis 06560 Valbonne, France – France
[9] Laboratoire GEGENAA – Université de Reims Champagne-Ardenne, 51100 Reims, France – France
[10] Institut des sciences de la Terre (ISTerre) – OSUG, INSU, Université Joseph Fourier - Grenoble I, Université de Savoie, IFSTTAR, IRD, CNRS : UMR5275 – BP 53 38041 Grenoble cedex 9, France
[11] EDF – Electricité de France - EDF : DIPNN-DI-TEGG – France
[12] Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – BP17 92262 Fontenay-aux-Roses Cedex, France

The 2019-11-1, Mw4.9 Le Teil earthquake occurred within the NE termination of the Cévennes faults system (CFS) in southern France, along the La Rouvière fault (LRF), an Oligocene normal fault which was not assessed to be potentially active. This shallow moderate magnitude reverse-faulting event produced a 5 km-long surface rupture and strong ground shaking. No evidence of previous quaternary activity was observed in the morphology, raising the question whether the LRF had been reactivated for the first time since the Oligocene or had broken the

*Speaker

surface in the past without being detected in the morphology. To answer this question, we carried out paleoseismological investigations along the LRF to analyze and characterize evidences of paleo-ruptures in Quaternary deposits. 15 trenches were dug along the section that broke in 2019. Several trenches yielded favorable Quaternary deposits (slope colluvium and eolian deposits lying against the ancient LRF normal fault mirror carved in the Barremian limestones) to document past-coseismic deformations. Using radiocarbon and OSL dates (from "bulks" collected into colluvium clayey-silty matrices) to constrain the age of the stratigraphic units, we interpret at least one event prior 2019, between 13.5 and 3.3 ka, within the central part of the LRF segment that broke in 2019. We also interpret a possible earlier surface-rupturing event within the northern part of this segment during the 16th century. Detailed logging of the faults and fabrics associated with these paleo events seem suggesting that their kinematic characteristics were similar to the 2019 event (reverse movement, _˜10 cm slip). Further investigations coupling sub-surface geophysical investigations and trenching are now carried out within the southern and northern segments of the LRF as well as along the other fault segments of the CFS.

Keywords: France, surface rupture, shallow event, moderate event, paleoevent, long recurrence intervals, Cévennes fault systeme

Long-term weakening and short-term rupture propagation processes of the intraplate Yangsan Fault, SE Korea, using low-angle borehole drilling

Chang-Min Kim * [1], Youngbeom Cheon† [1], Tae-Ho Lee [1], Jin-Hyuck Choi [1], Sangmin Ha [2], Jong Ok Jeong [3]

[1] Active Tectonics Research Center, Korea Institute of Geoscience and Mineral Resources – South Korea
[2] Department of Geological Sciences, Pusan National University – South Korea
[3] Center for Research Facilities, Gyeongsang National University – South Korea

The ~200-km-long Yangsan Fault Zone in SE Korea is an ideal case to study how faults evolve during the long geological times and produce the short-term earthquake cycles in the continental interior. To understand the long- and short-term deformation processes of the intraplate fault zone, we carried out the low-angle borehole drilling across the fault zone and displayed fault zone internal structure and mineral compositions obtained from the recovered drillcore samples. Since the Late Cretaceous, physico-chemical weakening processes have promoted the formation of a wide (~230 m in width) and complex fault zone architecture composed of clay-rich fault core strands and surrounding damage zones. The asymmetrical fault zone architecture is due to the different hardness between the two main wall rocks and consists of a 30-m-wide western damage zone (granite) and a ~200-m-wide eastern damage zone (sedimentary rock with felsic dikes). Of the five main strands (S1–S5) and numerous subsidiary core strands in the wide fault zone, strand S1 has accommodated the largest displacements. Moreover, microstructures of the smectite-rich, $<$ 2-cm-wide principal slip zone (PSZ) in the S1 exhibit several seismic slip indicators. These imply that the PSZ has acted as the main pathway for past seismic slip propagations. Our findings reveal that the deformations in the sedimentary rocks formed the asymmetrical wide fault zone over the long geological times, whereas the selective rupture propagations during the cyclical short-term seismic events along the narrow principal slip zone of S1.

Keywords: fault internal structure, asymmetric fault zone, multiple fault core, microstructure, Yangsan Fault

*Speaker
†Corresponding author: cheonyb@kigam.re.kr

Tectonic geomorphology of the Yangsan fault: regional implications for active tectonics in the intraplate region

Dong-Eun Kim * [1]

[1] Jin-Hyuck Choi – South Korea

Tectonic deformation can affect spatiotemporal patterns of landscapes. The development of tectonic geomorphology in the tectonically active region (e.g., San Andreas Fault Zone, Himalaya) is well understood. However, those in the intraplate region have rarely been quantified, although some paleoseismic studies have been carried out within several intraplate regions such as Australia and the New Madrid seismic zone in the central US.
The Korean Peninsula (KP), a tectonically inactive region with diverse lithology, has debated neotectonic activity for a long time because there is no clear geomorphic evidence related to the fault. However, the 2016 Gyeongju earthquake changed people's thinking that the earthquake could occur in the intraplate region. Recent research has found the active faults in the southeastern KP. The region provides a suitable field site to understand how tectonic deformation controls topography over the late Quaternary.

This study explored the structural and geomorphological evidence for recent tectonic activity in the Yangsan Fault System (YFS) in the Korean Peninsula. We use Light Detection and Ranging (LiDAR) with 0.5-1m/pixel to find tectonic deformation along the southern YFS. A morphostructural and geomorphological analysis was carried out using several topographic metrics like the local relief, slope variability, hypsometric integral, swath profiles, normalized concavity steepness (ksn), drainage basin shape index (Bs), asymmetry factor (AF), mountain front sinuosity (Smf) and the ratio of valley floor width to valley floor height (Vf). Then, we compare our result with a field-based result from previous paleoseismology studies. This work will demonstrate a quantitative relationship between topographic indices and deformation by active fault, which has important implications for improving landscape evolution models such as a poorly studied area in the intraplate region.

Keywords: tectonic geomorphology, topographic indice, intraplate

*Speaker

The silent and slow active faults of Germany: results from paleoseismological trenching

Klaus Reicherter * [1]

[1] RWTH Aachen University – Germany

Silent and slow faults represent one of the most intriguing problems in active tectonic studies, especially in Stable Continental Regions (SCR) or Active Intraplate Regions (AIR) like Central Europe. The term "silent faults" is used very variable, "silence" refers either to seismic activity, absence of seismogenic faulting (but possibly creep) or to the scarce geomorphic and geologic visibility of faults. Slow active faults are generally characterized by slip-rates $\leq$ 0.1 mm/yr, with limited potential to produce topographic expressions in humid/moderate climate. The slip-rate of a fault is a fundamental parameter that governs earthquake occurrence and seismic hazard in an area. Decreasing slip rates increase average recurrence intervals. Due to their long recurrence intervals, earthquakes on low slip-rate faults are often absent from the historical catalogues and the standard seismic hazard assessment processes. We present new fault data from several AIR (Rhine Graben rifts) and SCR regions in Germany, based on seismological, geophysical and trenching investigations. In general, recurrence periods are large and comprise 103-104 years. Slip rates are well below 0.5 mm/yr, or even $\leq$ 0.1 mm/yr. Holocene surface rupturing events are very rare, but present in the Lower and Upper Rhine grabens. Secondary earthquake effects observed more widely, also in other areas. However, some faults show marked linear scarps and topographic steps. Their preservation in an agriculturally used area is enigmatic: how can c. 50 cm high, single event scarps been preserved for 103-104 years? Geodetic techniques (GPS and DInSAR) are available for silent fault detection, signals are biased by groundwater extraction, vegetation and others obstacles. Some normal faults in the Lower Rhine Graben show evidence for the "Clustering and Quiescence" earthquake occurrence, which may explain the longevity of the scarps, and contrast the "One Shot" theory for SCR faults.

Keywords: paleoseismicity, Stable Intraplate Regions, active faults

*Speaker

Insights on fault reactivation during the 2019 November 11, Mw 4.9 Le Teil earthquake in southeastern France, from a joint 3-D geological model and InSAR time-series analysis

Léo Marconato *† [1], Philippe-Hervé Leloup [2], Cecile Lasserre [3], Romain Jolivet [4], Séverine Caritg [5], Raphael Grandin [6], Marianne Métois [7], Olivier Cavalié [8], Laurence Audin [9]

[1] Institut des Sciences de la Terre – Institut National des Sciences de l'Univers, Institut de recherche pour le développement [IRD] : UR219, Université Grenoble Alpes, Université Gustave Eiffel, Centre National de la Recherche Scientifique : UMR5275, Université Savoie Mont Blanc – France

[2] Laboratoire de Géologie de Lyon: Terre, Planètes, Environnement (LGL-TPE) – Université Claude Bernard-Lyon I - UCBL (FRANCE), CNRS : UMR5276 – Bâtiment Géode, Université Claude Bernard Lyon1 2 Rue Raphael DUBOIS 69622 Villeurbanne CEDEX, France

[3] Laboratoire de Géologie de Lyon - Terre, Planètes, Environnement [Lyon] – Université Claude Bernard - Lyon I – France

[4] Laboratoire de Géologie – Ecole Normale Supérieure de Paris - ENS Paris – France

[5] Bureau de Recherches Géologiques et Minières (BRGM) – BRGM – 3 avenue Claude Guillemen 45000 Orléans, France

[6] Institut de Physique du Globe de Paris – Universite de Paris, Institut de physique du globe de Paris, CNRS, F-75005 Paris, France – France

[7] Laboratoire de Géologie de Lyon - Terre, Planètes, Environnement [Lyon] – École Normale Supérieure - Lyon, Université Claude Bernard Lyon 1, Université de Lyon, Institut National des Sciences de l'Univers, Centre National de la Recherche Scientifique : UMR5276 – France

[8] geoazur – Université Nice Sophia Antipolis (UNS) – France

[9] Cycle sismique et déformations transitoires – Institut des Sciences de la Terre – France

The 2019, Mw 4.9 Le Teil earthquake occurred in southeastern France, causing substantial damage in this slow deforming region. Field observations, remote sensing and seismological studies following the event revealed that coseismic slip concentrates at shallow depth along a ˜5 km long rupture associated with surface breaks and a thrusting mechanism. We further investigate this earthquake by combining geological field mapping, 3-D geology, InSAR time-series analysis and a coseismic slip inversion. From structural, stratigraphic and geological data collected around the epicentre, we first produce a 3-D geological model of the region surrounding the rupture. Our model includes the geometry of the geological layers and the main faults, including the La Rouvière Fault (LRF), the Oligocene normal fault that ruptured during the earthquake. We generate a time-series of surface displacement from Sentinel-1 SAR data ranging from early 2019 January to late 2020 January. The spatio-temporal patterns of surface

*Speaker

†Corresponding author: leo.marconato@univ-grenoble-alpes.fr

displacement for this time span show neither a clear pre-seismic signal nor significant post-seismic transient deformation. We extract the coseismic displacement pattern from the InSAR time-series, highlighting along-strike variations of coseismic surface slip. The maximum relative displacement along the line of sight is up to _˜16 cm and is located in the southwestern part of the rupture. We invert for the slip distribution on the fault from the InSAR coseismic surface displacement field. Constraining our fault geometry from the geological model, acceptable fault dip ranges between 55◦ and 60◦. Our model confirms the reactivation of LRF, with reverse slip at very shallow depth and two main slip patches reaching, respectively 30 and 24 cm of slip, both around 500 m depth. We finally discuss how the 3-D fault geometry and geological structure may have impacted the slip distribution and propagation during the earthquake.

Keywords: Le Teil earthquake, slow deforming regions, 3D geology, InSAR, slip distribution

Looking for quaternary fault activities in the Armorican Massif (R8 FACT region): preliminary results of a geophysical analysis along the Southern Armorican Shear Zone.

Clément Perrin * [1,2], Antoine Mocquet [1], Mickaël Bonnin [1,2], Susan Conway [1], Eric Beucler [1,2]

[1] Laboratoire de Planétologie et Géosciences [UMR 6112] – Nantes université - UFR des Sciences et des Techniques, Centre national de la recherche scientifique - CNRS (France) – France

[2] Observatoire des Sciences de l'Univers Nantes Atlantiques – Université d'Angers, Institut National des Sciences de l'Univers, Conservatoire National des Arts et Métiers [CNAM], Centre National de la Recherche Scientifique : UAR3281, IMT Atlantique Bretagne-Pays de la Loire, Université Gustave Eiffel, Nantes Université – France

The northwestern part of France is characterized by a various set of major faults and shear zones, mostly inherited from past Protero-Paleozoic orogens (Cadomian, Variscan), and extensional (Meso-Cenozoic) and compressional (Cenozoic) events. Currently the region is located far from plate tectonic boundaries and is submitted to very low strain rates. Still, a fairly high activity of moderate size instrumental earthquakes (M_˜3-4) has been recorded in the region, where significant earthquakes have also been strongly felt in historical times.
The Southern Armorican Shear Zone (SASZ) is one of the major witnesses of the passed tectonic phases and is still well expressed in the morphology. The recent high resolution topographic data available from the French geographical institute (IGN) allow us to observe precisely multiple scarps in the morphology, and their relation with both river beds and recent alluvial deposits. We present different sites that would be of great interest for potential paleoseismological investigations in the near future. We show preliminary results of a geophysical analysis (electric and differential GPS) in one particular site situated in the north-west of Nantes where a scarp of the SASZ cross cuts a small quaternary alluvial fan. The across-strike geo-electric profiles indicate a large variation of apparent resistivity in good agreement with the surface scarp, which would highlight the transition between granitoids and quaternary sediments. It is not clear if the morphology is mainly related to a tectonic activity or a rheological contrast between the lithologies (or both). Future planned paleoseismological trenches will bring the ground truth that would help to answer this question.

Keywords: Armorican massif, shear zone, seismicity, lidar, geophysical analysis

*Speaker

Characterizating the Quaternary activity of the NE termination of the Cévennes Fault System and origin of the movement.

Nicolas Cathelin * [1,2], Jean-François Ritz [3], Stéphane Baize [4], Camille Thomasset [3,5], Matthieu Ferry [6], Kévin Manchuel [7], Romain Le Roux-Mallouf [8]

[1] Institut de Radioprotection et de Sûreté Nucléaire – Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – France
[2] Géosciences Montpellier – Université de Montpellier, Centre National de la Recherche Scientifique : UMR5243 – France
[3] Géosciences Montpellier – Institut National des Sciences de l'Univers : UMR5243, Université de Montpellier, Centre National de la Recherche Scientifique : UMR5243, Université des Antilles – France
[4] Institut de Radioprotection et de Sûreté Nucléaire – Institut de Radioprotection et de Sûreté Nucléaire, Institut de Radioprotection et de Sûreté Nucléaire, – France
[5] EDF – EDF – DIPNN - CEIDRE - TEGG - SGG – France
[6] Géosciences Montpellier – Géosciences Montpellier – France
[7] EDF – Electricité de France - EDF : DIPNN-DI-TEGG – France
[8] EDF-DI-DIPNN-TEGG – EDF – DIPNN - CEIDRE - TEGG - SGG, EDF – DIPNN, Aix-en-Provence, France – France

In November 2019, the Mw 4.9 Le Teil earthquake produced a 5km long surface rupture with a 5 to 22cm displacement. This event reactivated the La Rouvière fault (LRF) of NE-SW direction, an ancient Oligocene normal fault that belongs to the Cévenol Fault System (CFS), one of the greatest fault zones in metropolitan France. The LRF was not classified as a potentially active fault in the active fault database (BDFA). Only the Cévennes and Marsanne faults were considered as active in this database. This intraplate event raised several questions: (1) Has LRF already produced a surface rupturing earthquake in the past ? (2) Were other segments of the CFS active during the Quaternary period ? However, first paleoseismological investigations suggest that the LRF has already produced at least one surface rupture between 13.5 and 3.3ka ago (see Ritz et al. abstract). New paleoseismological studies are now being undertaken on Saint-Montan and Marsanne faults (SMF and MF). In parallel, geomorphological investigations on fluvial terraces in the Escoutay valley, normal to the CFS, suggest an acceleration in uplift since the late Pleistocene on the SE border of the Massif Central. This complementary approach aims to better appraise the temporal and spatial variations of the uplift on both sides of the CFS. Associated to the ongoing thesis of C.Thomasset, the goal of this project is to improve our understanding of the recent dynamics in the region which will lead to a reassessment of the seismic hazard in the area.

*Speaker

Keywords: Paleoseismology, Geomorphology, Quaternary, Le Teil, Intraplate

Paleoearthquake rupture scenarios and the role of fault geometrical complexity on the Yangsan Fault, SE Korea

Taehyung Kim * [1], Jin-Hyuck Choi [1], Youngbeom Cheon† [1], Tae-Ho Lee [1], Ho Il Lee [1], Yire Choi [1], Yann Klinger [2], Young-Seog Kim [3], Chung-Ryul Ryoo [1]

[1] Korea Institute of Geoscience and Mineral Resources – South Korea
[2] Institut de Physique du Globe de Paris – Lithosphere tectonics and mechanics – France
[3] Pukyong National University – South Korea

Defining the earthquake behavior of an intraplate fault is highly challenging because suitable geomorphic and stratigraphic evidence has been limited due to erosion and denudation processes and slow deformation of the fault. This study introduces the geomorphic and structural characteristics of the Southern Yangsan Fault (SYF), SE Korea. We conducted four trenches (Wolsan (WS), Miho (MH), Inbo north (IBN), and Inbo (IB)) along the SYF to determine the spatial and temporal history of paleoearthquakes. We recognized at least two paleoearthquake events at each trench site and constrained the timings of earthquakes based on results of radiocarbon and OSL age dating (28–16 ka, 39–35 ka, and 74–49 ka). We propose two possible rupture scenarios along the studied fault section during the Late Pleistocene: (a) the whole studied area slipped during each earthquake. (b) Individual partial ruptures along two segments of the section (the WS–MH and the IBN–IB sections) slipped during 39–35 and 74–49 ka, respectively. Here we comprehensively discuss the controlling factor for fault behavioral characteristics based on the fault geometry and timings of the earthquake events. We emphasize that the fault branching geometry between the WS–MH section and IBN–IB section could affect their slips in the second scenario. Furthermore, the timing(s) of the most recent earthquake for the SYF is much older than that of the northern part of the Yangsan Fault, which could be affected by the geometrically branching relationship with another major structure: the Ulsan Faults. Our findings suggest that the fault behavioral characteristics and earthquake history are significantly controlled by various scale-fault geometry.

Keywords: Intraplate fault, paleoseismic trench, strike, slip fault, rupture scenario, fault geometry

*Speaker
†Corresponding author:

Quantifying fault activity over different time scales in the Lower Rhine Graben, towards a new fault database for seismic hazard assessment.

Marthe Lefevre * [1,2], Kris Vanneste [1], Aurélia Hubert-Ferrari [2], Alain Demoulin [2]

[1] Observatoire royal de Belgique – Belgium
[2] Universite de Liege – Belgium

The Lower Rhine Graben (LRG) is an area of slow intra-plate extension (_˜0.1 +/- 0.03mm/yr) in north-western Europe. While the major active faults are well known, the activity of this complex system as a whole remains poorly understood, mostly because such slow deformation produces weak tectonic signal, easily overprinted by other processes. Thus, previous fault models omit structures presenting limited surface deformation and remain elusive about fault geometry and branching. Here, we present, a revised and homogeneous fault map, based on morphological observations of fault scarps and offset alluvial terraces realized on a high-resolution Lidar-based DEM, complemented by external information from paleoseismological and geophysical surveys. The eastern side of the graben exhibits clear scarps and sharp boundaries, while the western side presents smoother cumulative scarps, suggesting contrasting fault behavior across the graben. We compiled our active faults model in a database, including several levels of fault mapping (traces, fault sections, faults), with indications about the certainty of the faults identification and location. Another limitation for seismic hazard assessment in the area is the relative scarcity of fault-displacement data. In the southern LRG, a well-developed terrace allows to estimate the activity of most faults over the Quaternary, but such an extended marker is missing in the northern area. To complement these observations, we use several 3D-geological models to retrieve the vertical offsets at several locations along each fault, and obtain the spatial slip distribution at different timescales. We observe that, along individual faults, the slip profile evolves laterally and in time, showing some fault linkage, while at the scale of the graben borders the total slip is relatively homogenous. Moreover, although the surface-expression differs between the two sides of the graben, the total slip rates are fairly equivalent on both sides, suggesting a symmetrical extension, at least for the northern area.

Keywords: fault network, offset measurement, scarp morphology

*Speaker

Earthquake Ruptures and Seismotectonics of the NE Tien Shan

Chia-Hsin (wendy) Tsai *† [1], Richard Walker [1], Simon Daout [2], Christoph Grutzner [3], Galina Kulikova [4], Kanatbek Abdrakhmatov [5], Aidyn Mukambayev [6], John Elliott [7], Austin Elliott [8], Ed Rhodes [9], Andrew Ivester [9], Roberta Wilkinson [1]

[1] Department of Earth Sciences [Oxford] – United Kingdom
[2] CRPG, University of Lorraine – University of Lorraine, France – France
[3] Institute of Geological Sciences, Friedrich Schiller University Jena – Germany
[4] National Metrology Institute (Physikalisch-Technische Bundesanstalt) – Germany
[5] Institute of Seismology – National Academy of Sciences, Bishkek, Kyrgyz Republic, Kyrgyzstan
[6] Data Center of the Institute of Geophysical Researches – Kazakhstan
[7] COMET, School of Earth and Environment, University of Leeds – United Kingdom
[8] Earthquake Science Center, United States Geological Survey – United States
[9] Department of Geography, University of Sheffield – United Kingdom

The northeastern edge of the Tien Shan is the boundary between the active orogen and the stable shields of Kazakh platform and Dzhungarian Basin. As a tectonic transition zone within plate interiors in Central Asia, it has complicated and poorly-known modern and long-term crustal deformation. Nevertheless, this is a critical region for understanding the intracontinental lithospheric deformation and the earthquake occurrence related to the intraplate faults and their associated seismic hazards. Large historical earthquakes with magnitudes > Mw 7.5 have occurred in the northern Tien Shan within modern China. The surface ruptures of these-if any-are found to be elusive and the focal mechanisms are unclear. In contrast, large-magnitude earthquakes are absent from the historical records outside of China in the northeast Tien Shan. However, well-preserved paleo-earthquake ruptures can be found due to the arid climate, which allows the analysis of paleoseismicity and the creation of a database of large intraplate earthquake occurrence in addition to the historical events. We compile the previously reported surface ruptures triggered by the 1812 Nilke, 1906 Manas, and 1944 Xinyuan Earthquakes in China. We then re-estimate the magnitudes and relocate the hypocenters for the 1906 and 1944 events from their source parameters and integrate them with the geological observations to understand how they relate to the seismotectonics in the northeast Tien Shan. We also report on the NW-SE striking Dzhungarian fault (DZF) and the E-W striking Lepsy fault (LPF), which are the major boundary strike-slip structures. Using a combination of high-resolution digital elevation models and orthophotos, we identify the paleo-earthquake ruptures and present evidence that the DZF and its neighboring LPF may have ruptured together about 2-4 ka ago, with a rupture length of _˜300 km. This earthquake may have maximum displacements between 6 and 20 m and a magnitude over Mw 8.

*Speaker
†Corresponding author: chia-hsin.tsai@univ.ox.ac.uk

Keywords: Earthquake ruptures, Intraplate faults, 1906 Manas Earthquake, Dzhungarian Fault, Paleo, earthquakes

Cumulative and coseismic slip observed on the intracontinental Petrinja-Pokupsko Fault, source of the Mw 6.4 2020 Petrinja earthquake (Croatia): Insights from morphotectonic, paleoseismologic and geodetic data

Maxime Henriquet * [1], Branko Kordić [2], Josipa Maslač [2], Nikola Belić [2], Lara Wacha [2], Daniela Pantosti [3], Francesca Cinti [3], Stefano Pucci [3], Riccardo Civico [3], Alessio Testa [4], Paolo Boncio [4], Bruno Pace [4], Petra Jamšek Rupnik [5], Jure Atanackov [5], Marianne Métois [6], Cecile Lasserre [6], James Hollingsworth [7], Adrien Moulin [8], Stéphane Baize [9], Lucilla Benedetti [10]

[1] Centre européen de recherche et dénseignement des géosciences de lénvironnement – Institut de Recherche pour le Développement : UMR$_D$161, $AixMarseilleUniversité : UM34, CollègedeFrance : UMR7330, InstitutNationaldesSciencesdel'Univers, CentreNationaldelaRechercheScientifique : UMR7330, InstitutNationaldeRecherchepourl'Agriculture, l'Alimentationetl'Environnement – –France$

[2] Croatian Geological Survey (HGI-CGS), Milana Sachsa 2, 10000 Zagreb, Croatia – Croatia

[3] Istituto Nazionale di Geofisica e Vulcanologia - Sezione di Roma – Italy

[4] Università degli studi "G. dÁnnunzio" Chieti-Pescara [Chieti-Pescara] – Italy

[5] Geological Survey of Slovenia – Slovenia

[6] Laboratoire de Géologie de Lyon - Terre, Planètes, Environnement [Lyon] – École Normale Supérieure - Lyon, Université Claude Bernard Lyon 1, Institut national des sciences de lÚnivers, Centre National de la Recherche Scientifique : UMR5276, Institut national des sciences de lÚnivers, Institut national des sciences de lÚnivers, Institut National des Sciences de l'Univers, Institut national des sciences de lÚnivers – France

[7] Institut des Sciences de la Terre – Institut National des Sciences de l'Univers, Institut de recherche pour le développement [IRD] : UR219, Université Grenoble Alpes, Université Gustave Eiffel, Centre National de la Recherche Scientifique : UMR5275, Université Savoie Mont Blanc – France

[8] King Abdullah University of Science and Technology, Thuwal, Saudi Arabia – Saudi Arabia

[9] Institut de Radioprotection et de Sûreté Nucléaire – Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – France

[10] Centre européen de recherche et dénseignement des géosciences de lénvironnement – Institut de Recherche pour le Développement : UMR$_D$161, $AixMarseilleUniversité : UM34, CollègedeFrance : UMR7330, InstitutNationaldesSciencesdel'Univers, CentreNationaldelaRechercheScientifique : UMR7330, InstitutNationaldeRecherchepourl'Agriculture, l'Alimentationetl'Environnement : UMR1410 – –France$

The Mw 6.4 Petrinja earthquake of December 29, 2020, is among the strongest to have hit

*Speaker

Eastern Europe in recent decades. The comparison between the slip distribution of this event and the long-term cumulated deformation along the dextral Petrinja-Pokupsko Fault (PPKF) is critical to understand how strain is accommodated through time and space, and the characteristics of the seismic cycle in this slowly deforming region.
Based on field observations and high-resolution DEMs (LiDAR/Pleiades), the PPKF shows distributed surface deformation on subparallel and en échelon right stepping segments. To characterize the long-term slip model, we map and measure cumulative dextral offsets ranging from 5 to 250 m over 3-4 subparallel strands. Combining this with the dating of abandoned alluvial surfaces across the fault, we will estimate the PPKF fault-slip rate. First outcomes from a paleoseismological trench on the basin-ward strand at the southeastern portion of the 2020 rupture, reveals that the style of deformation is characterized by predominant ductile deformation that results in a distributed minor brittle response at the surface as observed in 2020. The long-term slip pattern is also compared to the 2020 slip model obtained from very near field GNSS dataset, optical image correlation and field observations. On the total _˜1.2 m right-lateral geodetic displacement, _˜30 % corresponds to localized surface offsets and the remaining strain seems to be rather distributed over a few hundred meters wide zone. Our geodetic slip models also reveal that that data require two slip patches which transition correlates with a gentle bending of the PPKF. A second subparallel branch SE of Petrinja could have significantly slipped during the earthquake, therefore accommodating part of the transpression.
Further work to better assess the seismic hazard and the role of this fault in the Adria-Europe convergence will be conducted by the EU Team.

Keywords: Petrinja, earthquake, slip rate, surface displacements, trench, GNSS, optical image correlation

Was the XXth century earthquake cluster in Mongolia a coincidence?

Yann Klinger *† [1], Yacine Benjelloun [2], Laurent Bollinger [3], Steven Forman [4], Angela Landgraf [5], Jin-Hyuck Choi [6], Sodnomsambuu Demberel [7], Solene Antoine [2], Ganbold Baatarsuren [7], Gantulga Bayasgalan [7], Youngbeom Cheon [6], Ganzorig Davaasuren [2,7], Gregor Lauer-Dunkelberg [8], Adiya Munkhsaikhan [7]

[1] Institut de Physique du Globe de Paris (IPGP) – INSU, IPG PARIS, Université Paris Diderot - Paris 7, Université de la Réunion, Centre National de la Recherche Scientifique : UMR7154 – IPGP, 1 rue Jussieu, 75238 Paris cedex 05 ; Université Paris Diderot, Bât. Lamarck A case postale 7011, 75205 Paris CEDEX 13, France

[2] Institut de Physique du Globe de Paris – CNRS : UMR7154 – France

[3] Commissariat à l'énergie atomique et aux énergies alternatives (CEA) – MESR, Ministère de la défense – BP12. 91680 BRUYERES LE CHATEL, France

[4] Baylor University – United States

[5] Nagra – Switzerland

[6] KIGAM – South Korea

[7] IAG – Mongolia

[8] University of Potsdam – Germany

The occurrence of large earthquakes in slow deforming continental areas is unusual. The occurrence of a series of such events in a short time is indeed even more unusual. During the last century four M8 events, including a series of 2 events in less than 2 weeks, struck Mongolia. This earthquake storm is often described as a consistent cluster that might be characteristic of earthquake activity in Mongolia on the long term. Here, we test this model by investigating the pair of earthquakes that occurred respectively along the Tsetserleg fault and the Bulnay fault, in northwestern Mongolia. Theses two M8 events, which are located only few kilometers from each other, rupture 14 days apart in July 1905. Using multi-stereo drone images we built high-resolution topography allowing mapping surface rupture in detail. More specifically, to compensate for the lack of direct markers to quantify lateral offsets, we used oblique crack width measurements as a proxy for surface slip, which yield average values ranging from 2 to 3 m for the horizontal coseismic slip. At one site, cumulative deformation was documented and it has been combined with IRSL dating of the geomorphic offset features to determine a minimum slip-rate of 0.28 mm/yr over a period of _˜27 kyr. Two fault-perpendicular trenches along the Tsetserleg fault allow identifying a minimum of three paleo-events including 1905. Time constraints based on OSL dating suggest that earthquake return time along the Tsetserleg fault is in fact 2.5 times longer than along the Bulnay fault. The date of the penultimate event along the Tsetserleg fault could be matched, at best, with the antepenultimate event along the Bulnay fault. Thus, we suggest that the remarkable 1905 earthquake sequence in Mongolia might be considered more as of a coincidence rather than reflecting a systematic pattern.

*Speaker

†Corresponding author: klinger@ipgp.fr

Keywords: slow deforming region, strike, slip, paleoseismology, earthquake cluster, Mongolia

Surface rupture of the 2020 Mw 5.1 Sparta, North Carolina, USA Earthquake and evidence of an active structure with recurrent Quaternary deformation

Paula M. Figueiredo * [1], Delwayne R. Bohnenstiehl [1], Arthur J. Merschat [2], Mark W. Carter [2], Karl W. Wegmann [1], Lewis A. Owen [1], Matthew C. Ricker [3]

[1] Department of Marine, Earth, and Atmospheric Sciences [NCSU] – United States
[2] United States Geological Survey [Reston] – United States
[3] Department of Crop and Soil Sciences [NCSU] – United States

On August 9, 2020, an Mw 5.1 earthquake was triggered on a previously unknown structure, now called the Little River fault. At its epicenter, near the town of Sparta, the Modified Mercalli intensity was VI-VII causing damage and economical loss of > US$24 million. Field surveys immediately identified a surface rupture, the first historically recognized in the eastern USA. The rupture trends N 110○, with reverse scarps and folding/flexure of the southern hanging wall, consistent with an oblique-reverse focal mechanism in a WNW-ESE trending and southwest-dipping structure. The rupture was initially mapped for _˜2 km and later extended to a length of _˜4.5 km based on high-resolution Lidar (_˜30 pulse/m2) acquired a few months after the earthquake. Initial observations suggested pre-existent discontinuities re-activated, whose tectonic activity was poorly understood. Geophysical surveys (ground-penetrating radar and electrical tomography resistivity) corroborated a near-surface meters-wide south-dipping fault zone along the co-seismic rupture. The sub-surface data was instrumental in guiding the location of a rupture-normal excavation to investigate the fault zone and deformation before the 2020 event. The trench exposed a complex fault zone _˜15 m wide, with WNW-ESE to NW-SE strands (some with oblique striations), where a low-grade metamorphosed greywacke overthrusts amphibolite. The 2020 surface rupture was accommodated by three reverse-fault strands, with a total along-fault displacement of _˜50 cm. A sequence of Pleistocene soil and colluvium overlays the weathered bedrock. This sequence in the hanging wall is locally disturbed in close association with fault strands, related with previous deformation. Preliminary luminescence data suggest an age of late Pleistocene for the upper soil layers. These observations indicate that the structure that ruptured during the Mw 5.1 Sparta earthquake is an active Quaternary reverse fault that strikes NW-SE, which is oblique to the NE-SW structural and topographic trends of the Southern Appalachian Mountains.

Keywords: Intraplate earthquakes, moderate magnitude surface rupture, Quaternary fault reacti-

*Speaker

vation

Paleoseismic characteristics based on geomorphological and structural geological analysis for the central part of the Ulsan fault zone, SE Korea

Kiwoong Park * [1], Sambit Prasanajit Naik [1], Ohsang Gwon [1], Hyeonjo Shin [1], Young-Seog Kim† [1]

[1] Pukyong National University – South Korea

The Ulsan fault zone is NNW-SSE trending reverse fault with a length of approximately 50 km from Ulsan to Gyeongju city in the southeast Korean Peninsula. The study area is located in the central part of the Ulsan fault zone, where Cretaceous and early Tertiary granitic bedrock are covered by the Quaternary deposits. Large-scale alluvial fans from the eastern mountainous areas are linearly arranged in the N-S direction and a large number of Quaternary faults displacing the alluvial fan have been reported. However, the relationship between these previously reported faults and the kinematic characteristics of the Quaternary faults has not been understood. Fault core and fault damage zone with continuous vertical separation of approximately 1-2 m are continuously developed on the slope of the valley. The trench location was selected based on the results of the geomorphic analysis and field survey. In the trench section, the east dipping fault indicates predominantly reverse movement with a minor strike-slip component. The unconsolidated sediments are subdivided into 10 unit layers based on grain type, size, color, roundness of gravel, and degree of sorting. The slickenline and vertical separation of the cumulative displacement indicate at least 18 m of net displacement. In particular, it is notable that the dip of the fault plane varies from 30◦ to 71◦ to 12◦ from the bottom to the top. It seems to reflect complex changes in physical properties, kinematic properties, and fault geometry along this fault. Based on the OSL ages of the topmost sedimentary unit, the timing of the most recent event is younger than 43±3 ka.

Keywords: active fault, Ulsan fault zone, trench, thrust system

*Speaker

†Corresponding author: ysk7909@pknu.ac.kr

Spatial and temporal variations in slip rate across extensional fault networks

Zoë Mildon *† [1], Billy Andrews [1], Gerald Roberts [2], Joanna Faure Walker [3], Chris Jackson [4], Francesco Iezzi [5]

[1] School of Geography, Earth and Environmental Sciences, University of Plymouth – United Kingdom
[2] Department of Earth and Planetary Sciences, Birkbeck, University of London – United Kingdom
[3] Institute for Risk and Disaster Reduction, University College London – United Kingdom
[4] Department of Earth and Environmental Sciences, University of Manchester – United Kingdom
[5] Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse, Università degli Studi di Napoli Federico II, Napoli – Italy

Temporal variations in slip rate, implying clustering/anti-clustering of earthquakes, have been observed across a range of tectonic scenarios. On millennial time scales, slip rate variability has been recognised in areas of active continental extensional. For example, in Italy and Greece, 36Cl sampling of limestone normal fault scarps have been used to invert for slip history over the Holocene (e.g. Cowie et al., 2017; Iezzi et al., 2021; Mildon et al., *subm.*) and these records show that the slip rates vary at the sampled location(s), with activity switching between across-strike faults.
To extend our timescale of observation, seismic reflection datasets can be used to study how slip rates vary over millions of years, for both inactive and active fault systems. These datasets can be used to explore temporal and spatial slip rate variations, and can be used to examine whether slip rate variations are consistent along-strike of an individual fault or across a fault network. Using a 3D seismic dataset from the NW shelf of Australia, faulted horizon offsets have been extracted across a network of faults, which represent a time span of 60 Ma active extension. These data show that the slip rates on individual faults vary temporally by up to an order of magnitude, with the locus of maximum slip rate moving along the fault in different time periods. For networks of across-strike faults, we see evidence of faults switching between low and high slip rate, though these variations are not always consistent along-strike.
The combination of millennial and million year timescale datasets show that variable slip rate and switching of activity are consistent observations, and furthermore allows us to investigate the spatial variability of slip rate changes in greater detail than field-based studies alone.

Keywords: normal faults, slip rate, fault interactions, 3D seismics

*Speaker
†Corresponding author: zoe.mildon@plymouth.ac.uk

Paleoseismic characterization of the eastern Rhine Graben Boundary Fault (RGBF), Southern Germany

Sara Pena Castellnou *† [1], Jochen Hürtgen [1], Stéphane Baize [2], Hervé Jomard [3], Edward M. Cushing [3], Thomas K. Rockwell [4], Gordon Seitz [5], Francesca R. Cinti [6], Wahid Abbas [7], Frank Preusser [8], Daniela Mueller [8], Joachim Ritter [9], Klaus Reicherter [1]

[1] RWTH Aachen University – Germany
[2] Institut de Radioprotection et de Sûreté Nucléaire – Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – France
[3] Institut de Radioprotection et de Sûreté Nucléaire – Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – France
[4] Department of Geological Sciences, San Diego State University, San Diego, CA – United States
[5] California Department of Conservation, California Geological Survey, San Mateo, CA – United States
[6] Istituto Nazionale di Geofsica e Vulcanologia, Roma – Italy
[7] Department of Earth Sciences, COMSATS University Islamabad, 22060, Abbottabad – Pakistan
[8] Institute of Earth and Environmental Sciences, University of Freiburg – Germany
[9] Karlsruhe Institute of Technology, Geophysical Institute – Germany

The Upper Rhine Graben (URG) is one of the most seismically active regions in the plate interiors of Europe and hosts a set of major faults that have caused damaging earthquakes in historical times (e.g., the 1356 Basel earthquake). Although seismic activity poses a significant threat to the dense population and critical facilities, few studies have documented the paleoearthquake history and associated seismic hazard of these faults. Our research continues the first paleoseismic studies in the eastern Rhine Graben Boundary Fault (RGBF), engaged by the cooperation of IRSN (France) and the RWTH Aachen University (Germany) by studying its neotectonic imprint in the landscape and examining its longer history of surface rupturing earthquakes by combining LiDAR-based DEM analysis, shallow geophysics, and paleoseismological trenching. Following up on the previous surveying studies, we trenched in two target sites. In Ettlingen-Oberweier (south of Karlsruhe), trenches along and across the secondary fault scarp of the eastern RGBF exposed a fault zone spreading in multiple *en echelon* left-lateral branches in a negative flower structure. We identified a minimum of three paleoearthquakes, the youngest of which occurred after the LGM, with 0.3-0.6 m of vertical displacement per event and amounts to roughly 2m left-laterally. Near the village of Tunsel (south of Freiburg, 120 km south of Ettlingen-Oberweier), we excavated trenches across the Rhine River Fault (RRF) scarp, parallel to the main eastern RGBF within the graben, which cuts the distal part of the Neumagen-Möhlin alluvial fan. We observe a minimum of two seismic events, the youngest post-LGM, with cumulative 0.5m of vertical separation and clear evidence of left-lateral kinematics. In both study sites, trenches exposed surface rupturing earthquakes providing the first

*Speaker
†Corresponding author: s.pena-castellnou@nug.rwth-aachen.de

evidence of Late Pleistocene and Holocene tectonic activity in the eastern margin of the URG and contributing significantly to the completeness of its earthquake history.

Keywords: Neotectonics, Upper Rhine Graben, Tectonic geomorphology, Paleoseismology, Intraplate tectonics

Slip distribution and segmentation of the Ar-Hötöl surface rupture along the Khovd Fault (Mongolian Alay)

Matthieu Ferry * [1], Davaasambuu Battogtokh [1,2], Jean-François Ritz [1], Ulzibat Munkhuu [2]

[1] Géosciences Montpellier (Uni. Montpellier - CNRS) – Institut National des Sciences de l'Univers : UMR5243, Université de Montpellier, Centre National de la Recherche Scientifique : UMR5243, Université des Antilles – France

[2] Institute of Astronomy and Geophysics, Mongolian Academy of Sciences – Mongolia

The Khovd fault is one of the major active faults of the Altay but has been little studied. Detailed mapping based on satellite imagery shows that the Khovd structure exceeds 550 km in length and displays different types of complex rupture segmentation, fresh and mature surface ruptures and a number of co-seismic and cumulative offsets along its entire length.

We present a 1:200,000 scale map of the Ar-Hötöl surface rupture along the Khovd Fault in the Mongolian Altay, presumed to be the surface expression of a Mw ˜ 7.8 earthquake that was felt regionally in 1761 CE. The detailed mapping is based on a multi-scale approach combining a range of airborne and terrestrial imaging and topographic techniques: Sentinel-2, Pleiades, TanDEM-X, UAV, and terrestrial laser scanning. This effort led to the detailed quantification of right-lateral and vertical offsets ranging from ˜ 1 m to ˜ 4 km over a continuous rupture length of 238 km. The distribution of the smaller offset class documents the surface deformation associated with the last surface-rupturing earthquake. Its analysis yields a robust segmentation model comprising 6 segments 18 to 55 km in length, a maximum co-seismic slip value of 4.5 m ± 0.5 m located near the center of the rupture. Our detailed remote sensing and field observations precise the varying kinematics along strike, bring new evidence of repeated faulting and confirm a moment magnitude of 7.8 ± 0.3.

The aim of the present research work is to reveal the main sources of potential destructive earthquakes by identifying the location of past large earthquakes along the fault and estimate their magnitude and recurrence period. Our results would contribute to improve seismic hazard estimation for population of the Altay Mountains.

Keywords: Active faulting, surface rupture, seismic hazard, Altay Range

*Speaker

Archeoseimology and historical earthquakes

Investigating Holocene earthquakes along an Oceanic Transform Fault: the Húsavík-Flatey Fault in northern Iceland

Remi Matrau * [1], Yann Klinger [2], Thorvaldur Thordarson [3], Armann Hoskuldsson [3], Esther Gudmundsdottir [3], Jonathan Harrington [1], Ulas Avsar [4], Sigurjon Jonsson [1]

[1] King Abdullah University of Science and Technology – Saudi Arabia
[2] Institut de Physique du Globe de Paris – Institut National des Sciences de l'Univers, IPG PARIS, Université de la Réunion, Centre National de la Recherche Scientifique : UMR7154, Université Paris Cité : UMR7154 – France
[3] Institute of Earth Sciences, University of Iceland – Iceland
[4] Middle East Technical University [Ankara] – Turkey

The Húsavík-Flatey Fault (HFF) in northern Iceland is a 100 km-long right-lateral transform fault connecting the onshore Northern Volcanic Zone to the offshore Kolbeinsey Ridge and accommodating, together with the Grímsey Oblique Rift (GOR), ~18 mm/yr of relative motion between the Eurasian and North American plates. Significant earthquakes occurred on the HFF in 1755, 1838 and 1872 with estimated magnitudes of 6.5-7. However, historical information on past earthquakes prior to 1755 is very limited in both timing and size. The HFF is a unique location, allowing us to study the Holocene activity of an Oceanic Transform Fault and to bring insights on the kinematics of an Oceanic Fracture Zone.
We excavated six trenches in two locations along the HFF, five in a small pull-apart basin (Vestari Krubbsskál) and one in an alluvial fan (Traargeri). We used volcanic ash layers (tephra) in Vestari Krubbsskál and Traargeri, together with birch wood samples from Traargeri to constrain the timing of past earthquakes.
Trenches at both sites show dip-slip displacement, in addition to strike-slip, well correlated with their larger scale topographies (pull-apart basin in Vestari Krubbsskál and 45 m-high fault scarp in Traargeri). We mapped layers, cracks and faults on all trench walls to build a catalogue of Holocene earthquakes. We identified eight events in the last 6000 years, based on upward terminations of cracks and retrodeformations of the layers. Our interpretation yields fewer major earthquakes than expected from the last 300 years record. This suggests that large earthquakes (around magnitude 7) are probably rare and the typical earthquakes of the HFF have magnitudes of 6-6.5 producing limited topsoil deformation. Our interpretation also suggests that the Holocene slip rate may be slower than the current geodetic slip rate (6 to 9 mm/yr), although secondary onshore sub-parallel fault strands could accommodate part of the deformation.

*Speaker

Keywords: tephra, paleoseismology, trench

Historical earthquakes in Lower Silesian Block - an archeoseismological approach

Krzysztof Gaidzik * [1], Miklós Kázmér [2,3]

[1] Institute of Earth Sciences, University of Silesia, Sosnowiec, Poland – Poland
[2] MTA-ELTE Geological, Geophysical and Space Science Research Group, Budapest, Hungary – Hungary
[3] Department of Palaeontology, Eötvös University, Budapest, Hungary – Hungary

Archeoseismology, due to the common lack of written testimonies and incompleteness of seismic catalogs, might play a crucial role in filling the gaps in historical earthquake records and, therefore, in improving the seismic hazard assessments. This is particularly true for regions opulent in archeological sites and/or medieval structures (especially churches). This task is even more relevant and challenging in intraplate regions characterized by the low deformation rate and associated low to moderate seismicity with an usually long recurrence period.
Lower Silesian Block in the NE Bohemian Massif shows a long history of human occupation with abundant medieval to XX-century buildings presenting a rich history of damage/repair/renovation suitable for archeoseismological studies. The unit is cut by the 200-km long Sudetic Marginal Fault (SMF), i.e., one of the most prominent tectonic zones in central Europe that exhibits the pronounced morphotectonic escarpment of the Sudetic Mountains front. Its Quaternary activity with a prehistoric earthquake of minimum moment magnitude M 6.3 and the inferred slip rate of about 0.03 mm/year have been corroborated. Moreover, several historical earthquakes since the XV century have been reported.
We present here the results of a comprehensive archeoseismological study of $>$ 50 churches located in the Lower Silesian Block adjacent to the SMF. We report several structures with unusual buttresses, tilted inward/outward walls, dropped keystones, displaced masonry, shifted blocks and/or columns, etc. Based on the history of deformations and repairs, our results suggest that some sites experienced more than one moderate to destructive earthquake. For ten of the studied sites, the assigned archeo-intensity exceeds VIII. Further studies are needed to date the recorded seismic events and establish their potential sources.

Keywords: Archeoseismology, historical earthquakes, Sudetic Marginal Fault, archeointensity

*Speaker

Assessing historical earthquake sequences with Coulomb stress models

Manuel-L. Diercks *† [1,2], Zoë Mildon [1], Sarah J. Boulton [1], Ekbal Hussain [2]

[1] School of Geography, Earth and Environmental Sciences, University of Plymouth – United Kingdom
[2] British Geological Survey – United Kingdom

Fault-based deterministic seismic hazard assessment (SHA) is an increasingly popular addition to SHA. Several studies have modelled Coulomb stress transfer (CST) throughout earthquake sequences spanning centuries to millennia. These models reveal insights into the stress state of fault networks but depend on a reliable correlation of recorded earthquakes and source faults. Historical earthquake catalogues list the timing and approximate location of earthquakes, but rarely specify the source fault(s). Only for well-studied faults/events can this gap be filled by historic, archaeoseismologic or paleoseismologic data. In this study, we assess a sequence of 14 earthquakes in the Büyük Menderes Graben (SW Turkey), between 1645 and 1986AD. We present an approach to assess historical earthquake sequences, aiming to (1) gain knowledge on historical earthquakes and (2) improve CST-based SHA. Firstly, for each earthquake we elaborated multiple possible rupture scenarios based on available historical and geological information. Scenarios may vary in the location (source fault), magnitude and other rupture parameters, but all variations represent potentially plausible scenarios of the event, corresponding to available knowledge. Secondly, we modelled CST for all possible combinations of rupture scenarios of the earthquake series, resulting in > 1000 modelled earthquake sequences. Finally, we evaluated the plausibility of each of these solutions based on physical criteria, such as the stress state of the rupture planes before and after the earthquakes, stress changes on the fault network, and correlation of recent seismicity with the stress field induced by an earthquake sequence. For example, solutions featuring high CST on rupture planes prior to earthquakes are more plausible than solutions with low or negative CST. As earthquakes never occur independently, sequences are evaluated as a whole. This technique improves the reliability of historical data and resulting models.

Keywords: fault based deterministic seismic hazard analysis, historical earthquakes, Coulomb stress modelling

*Speaker
†Corresponding author: manuel-lukas.diercks@plymouth.ac.uk

A paleoseismic attempt using archeoseismology in a region of low intraplate seismicity in the Chalk of the Paris Basin, Normandy, France. Is the Fécamp-Lillebonne fault always active ?

Anne Duperret * [1], Sara Vandycke [2], Elisabeth Robert-Barzman [3], Tassadit Kaci [4]

[1] Laboratoire Ondes et Milieux Complexes – CNRS : UMR6294, Normandie Univ, UNILEHAVRE – France
[2] Université de Mons, Mining Engineering unit (UMons) – 20, place du Parc, 7000 Mons, Belgium
[3] Identités et Différenciations de l'Environnement des Espaces et des Sociétés (UMR 6266 IDEES Le Havre) – Normandie Université, UNILEHAVRE, CNRS : UMR6266 – 25 rue Philippe Lebon, 76600 Le Havre, France
[4] Laboratoire Ondes et Milieux Complexes – Université Le Havre Normandie, Centre National de la Recherche Scientifique : UMR6294 – France

The northwestern part of the Paris Basin in France presents mostly a very low level of seismic hazard with very weak and sparse historical and instrumental seismicity. A swarm of shallow earthquakes (with a maximal Mw reaching 2.9) is recorded in the Chalk of Normandy. Swarm extends to about 40 km on each part of the Fécamp-Lillebonne fault (FFL), suspected to be active during the Quaternary in the french BDFA database. The FFL is a N150○ normal dextral fault extending over 30 km inland from the Channel coast to the Seine river. The FFL prolongates offshore in the Channel, where it shows a NW-SE trend and is connected to the east with an orthogonal N60○E fault system called the Villequier-Pavilly normal fault (VPF).
Only part of the FFL may be recognized in the chalky landscape, due to later valley incisions and an historic seismic activity is recorded near. We thus study correlations between the historic seismic activity location and the direct disturbances recorded on historic buildings, such as at the Angerville-Bailleul castle, built in 1560 at 2km SE of the VI MSK 10th July 1847 earthquake and the Tancarville castle built between 1709 and 1730 at 7 km to the east of the VI MSK, 12 dec 1848 earthquake.

Each castle shows potential record of the seismic activity, with a dextral strike-slip fault N150○E reported on the bounding wall of the vegetable garden at Angerville-Bailleul castle and a sinistral strike-slip shift observed between the stones of an exterior staircase, along a N135○E axis at Tancarville.
Even if signs of earthquakes on historical buildings are tenuous, they could represent some indices of a very recent activity of the FFL. It could be confirmed with a trench to better evidence the seismic cycle through the record of paleo-earthquake within Plio-Pleistocene deposits.

*Speaker

Keywords: fault, Paris basin, low seismicity, historic record

Paleo-tsunami records response to submarine volcano activities in Korea

Hoil Lee * [1], Yire Choi† [1], Sang Deuk Lee [2], Ji Hye Han [2], Jin-Hyuck Choi [1]

[1] Korea Institute of Geoscience and Mineral Resources (KIGAM) – South Korea
[2] Nakdonggang National Institute of Biological Resources (NNIBR) – South Korea

It is important to assess geologic hazards associated with tsunamis for the east coast of the Korean Peninsula because 1) there are dense industrial facilities, including nuclear power complexes, and densely populated cities, and 2) there have been reported active faults and volcanos under the East Sea. Although tsunamis in the east coast areas were reported on historical documents, it has been rarely studied to detect geologic records of tsunami deposits and to investigate their tectonic origins. In this study, tsunami records were traced from core samples of the lagoon where locates close to the east coast through chemical and biological approaches, and the time and origin of the tsunami were considered. The study area begins to be affected by the transgression from about 9–8 ka due to global sea-level rise after LGM. Microfossil analysis results show that *Dictyocha fibula* (microalgae), known as a high-salinity pelagic species, is dominant around 8.2 ka. In Bacterial diversity analysis, *Sulfurimonadaceae* and *Alicyclobacillus ferrooxydans* are characteristically distributed only at about 8.8–8.2 ka, 7.3–7.1 ka, and 0.5 ka. These are known to inhabit mainly pelagic redox zones and seamounts generated by the intense volcanic activity of hydrothermal vents. These paleo-archive results are supported by the Fe/S ratio in the coreXRF data to confirm the Fe fluctuation trend related to volcanism. Coincidentally, the 8.8–8.2 ka period coincides with the volcanic activity period (U-3) of Ulleung Island located in the East Sea. Therefore, it is considered that volcanic activity occurred on Ulleung Island and its surrounding seabed for at least 8.8–8.2 ka, which caused a tsunami and affected the east coast of Korea. In addition, the rest of the period can be used as direct evidence to reveal the timing of the submarine volcanic activity around Ulleung Island.

Keywords: Tsunami, submarine volcano, Ulleung Island, Korea

*Speaker
†Corresponding author:

The twisted gate – repeated destructive earthquakes in Cluj-Napoca, Transilvania

Miklós Kázmér * [1,2], Erzsébet Győri [3], Szilárd Papp [4], Radu Lupescu [5], Viorica Rusu [6], Krzysztof Gaidzik [7]

[1] MTA-ELTE Geological, Geophysical and Space Science Research Group, Budapest, Hungary – Hungary
[2] Department of Palaeontology, Eötvös University, Budapest, Hungary – Hungary
[3] Kövesligethy Radó Seismological Observatory, Institute of Earth Physics and Space Science, Budapest – Hungary
[4] Museum of Fine Arts, Budapest – Hungary
[5] Department of European Studies, Sapientia University, Cluj-Napoca – Romania
[6] National Museum of Transylvanian History, Cluj-Napoca – Romania
[7] Institute of Earth Sciences, University of Silesia in Katowice, Sosnowiec – Poland

Seismicity of Romania is the highest among the intra-plate regions of Europe, attributed to the intermediate-depth Vrancea seismic zone. Other parts of the country are considered sesmically less hazardous, based on more than 120 years of instrumental observations, and a limited number of historical records. The Transylvanian Basin, enclosed by the Carpathians, seems especially quiet, both by the lack of instrumental data and sparse historical evidence. A systematic archaeoseismological survey was started; initial results indicate that there were several destructive earthquakes in Transylvania in historical times. We report here severe earthquake-induced deformation from the 3rd to the 18th century within Cluj-Napoca. Sparse archaeological records, mostly from rescue excavations of Roman Napoca below modern Cluj city revealed a laterally extensive, liquefied cultural layer: an intraclast breccia of terrazzo floor, and a severely deformed, stone-paved courtyard, bearing differential subsidence of 90 cm amplitude through a 9 m long, stone-paved courtyard. The deformed floor is overlain by a coherent, toppled wall with arched window opening. Further sites with tilted floors were excavated citywide. The liquefaction event is dateable to the late 3th century. The adjacent St. Michael church, built in in 1316-1349, suffered severe destruction. Pervasive fracturing and twisting of walls and gates, down to floor level was followed by restoration, was completed in 1450. The next earthquake in 1863 caused the loss of the tower. Dropped keystones, folded, fractured, and collapsed walls and floors allow intensities up to IX to be attributed to each events. Evidence for three destructive earthquakes within the past two millennia obliterates the myth of seismic quiescence of the Transylvanian Basin.

Keywords: antiquity, middle ages, archaeoseismology, Romania

*Speaker

Coherent toppled walls – an archaeoseismological assessment

Miklós Kázmér * [1,2], Krzysztof Gaidzik [3]

[1] MTA-ELTE Geological, Geophysical and Space Science Research Group, Budapest, Hungary – Hungary
[2] Department of Palaeontology, Eötvös University, Budapest, Hungary – Hungary
[3] Institute of Earth Sciences, University of Silesia, Sosnowiec, Poland – Poland

Toppled walls are walls that fell off their foundations in a coherent way, maintaining their integrity, the original pattern of component blocks. We offer a set of observable and measurable parameters to describe these walls for archaeoseismological analysis and interpretation.

- Material (masonry and/or rubble)
- Brick, stone, adobe, earth
- Mortar (type, thickness), if any
- Any openings, arches in wall, maintained during fall
- Height / length / thickness / weight = dimensions / volume
- How many leaves (1-2-3)? How many remained (any robbing)?
- Way of lying on the floor: coherent / row-by-row imbricated / random
- Internal deformation / separation of courses
- Fallen inwards / outwards of the edifice
- Collapse azimuth (for fault attribution)
- Deformation of foundation and lowest courses of masonry (any shear)
- Distance of lowest row of masonry from the foundation (for acceleration)
- Function of the walled edifice
- Intensity of shaking
- Age of construction
- Age of destruction

*Speaker

- Age of restoration

The purpose of recording these parameters is to:

- Argue for a destructive earthquake
- Date earthquake
- Estimate intensity
- Assess the location of the causative fault
- Assess mechanism of faulting
- Calculate peak ground acceleration
- Internal deformation might yield yet unknown information about the shaking / collapse process.

Keywords: collapse, archaeoseismology, wall

M> 7.5 Earthquake on the Pallatanga Fault evidenced by archeoseismic damage and secondary landslides in Riobamba region of Ecuador

Laurence Audin *† [1,2], Stéphane Baize [3], Hervé Jomard [3], Alexandra Alvarado [4]

[1] ISTerre – Institut des Sciences de la Terre : UMR5275 – France
[2] Institut de Recherche pour le Developpement – Institut de recherche pour le développement [IRD] : UR219 – France
[3] Institut de Radioprotection et de Sûreté Nucléaire – Institut de Radioprotection et de Sûreté Nucléaire (IRSN), PSN-EXP/SES/LMAPS, 31, avenue de la Division Leclerc, BP 17, 92262 Fontenay-aux-Roses, CEDEX, France – France
[4] IGEPN – Ecuador

The Riobamba event (Ecuador), in 1797, is one of strongest crustal earthquake known in South America and has been reported by Alexander von Humboldt, when he visited the area in 1801–1802. Its surface rupture and strong co-seismic imprint is still preserved in the landscape, and has been studied in paleoseismic trenches (Baize et al., 2014, 2020). But the region of Riobamba, located on the Pallatanga strand of the North Andean Sliver boundary in Ecuador, still exhibits some rare historical monuments from the XVI to XVIII centuries. We focused on those, and discover that they still bear classical evidences of past seismic shaking: repairs, broken corners and fissures (Earthquake Archeological Effects). Locally along the fault trace, we identified three sites : (1) the repaired walls of a damaged mill (2) dated damage and reconstructions of Colta and Sicalpa Viejo churches near Cajabamba, as well as (3) major landslides induced co seismically along the fault strand as the one that buried the old Cajabamba city. The spatial distribution, ages of these three sites points toward a superficial, crustal earthquake related to the Pallatanga Fault as a source for the damage. Among the potential events, the 1797 Riobamba earthquake is the best candidate to account for those damage on each site. Given the numerous 117 intensities reported in Ecuador up to Quito north, its magnitude has been bracketed between Mw 7.6 and 8.3 (Beauval et al., 2010). We here propose that, even sparse, such archeo/paleo studies could be valuable to strengthen the seismic knowledge in Latin America for the historical earthquakes as well as for the archeological time period where pre historical monumental buildings are still standing (Mexico and Peru).

Keywords: Historical Earthquake, Archeology, Active Tectonics, Ecuador, South America

*Speaker
†Corresponding author: Laurence.Audin@ird.fr

The largest earthquake and tsunami of the last five centuries in Mexico uncovered in historical and geological records

María-Teresa Ramírez-Herrera * [1], Néstor Corona [2], Jan Cerny [1], Rocío Castillo-Aja [3], Diego Melgar [4], Marcelo Lagos [5], Avto Goguitchaichvili [6], María Luisa Machain [6], María Ortuño [7]

[1] Universidad Nacional Autónoma de México, Laboratorio de Tsunamis y Paleosismología – Mexico
[2] El Colegio de Michoacán – Mexico
[3] Universidad de Guadalajara – Mexico
[4] Department of Earth Sciences, University of Oregon, Oregon – United States
[5] Pontificia Universidad Catolica de Chile – Chile
[6] UNAM – Mexico
[7] Ciencias de La Tierra, Universidad de Barcelona – Spain

Instrumental seismic records have a time interval of about one hundred years, while the recurrence interval for great to large earthquakes might expand to hundreds or even thousands of years. Thus, instrumental seismicity records provide a short timespan to understand earthquake recurrence of large and great events, and consequently to assess earthquake hazard. Historical and geological investigations enlarge the earthquake record and provide seismic data of several hundreds to thousands of years, of both cortical and offshore faults (megathrusts faults). However, sometimes incomplete records due to poor preservation of documents and/or geologic evidence might have less precision. Mexico is one of the most seismically active places on Earth, located in the Circum-Pacific Belt, and in a complex tectonic setting where five tectonic plates interact. The interaction of the North American plate and the subduction of Cocos and Rivera plate produces the most seismically active zone in Mexico where the largest earthquakes occur, and some of them have triggered tsunamis, in central and southern Mexican Pacific coast. The largest instrumentally recorded earthquakes, all of them tsunamigenic, took place along the subduction boundary one June 3, 1932 (Mw 8.2) in Colima-Jalisco, September 19, 1985 (Mw 8.06) in Michoacán, October 9, 1995 (Mw 8.0) in Colima, and September 8, 2017 (Mw 8.2) in Tehuantepec. We present here results of the largest earthquake M8.6, and its tsunami, recorded in Mexico in 1787., based on historical documents, historical testimonies and historical maps, and preserved in the geologic record. Our results on tsunami and earthquake modeling confirm a large earthquake that produced coastal coseismic subsidence and a tsunami that flooded more than _˜3 km inland.

Keywords: historical records, megathrust earthquake, tsunami, modeling, subsidence

*Speaker

Surface expression of historical earthquakes in central and eastern Nepal

Laurent Bollinger * [1], Magali Riesner [1,2], Yann Klinger [3], Magali Rizza [2], Som Nath Sapkota [4], Chanda Basnet [4], Cagil Karakas [5], Paul Tapponnier [5]

[1] CEA/DAM/DIF/DASE – CEA – France
[2] Centre européen de recherche et dénseignement des géosciences de lénvironnement – Institut de Recherche pour le Développement : UMR$_D$161, $AixMarseilleUniversité : UM34, CollègedeFrance : UMR7330, InstitutNationaldesSciencesdel'Univers, CentreNationaldelaRechercheScientifique : UMR7330, InstitutNationaldeRecherchepourl'Agriculture, l'Alimentationetl'Environnement : UMR1410 - -France$
[3] Institut de Physique du Globe de Paris (IPGP) – INSU, IPG PARIS, Université Paris Diderot - Paris 7, Université de la Réunion, Centre National de la Recherche Scientifique : UMR7154 – IPGP, 1 rue Jussieu, 75238 Paris cedex 05 ; Université Paris Diderot, Bât. Lamarck A case postale 7011, 75205 Paris CEDEX 13, France
[4] National Seismological Centre Nepal – Nepal
[5] Earth Observatory of Singapore – Singapore

The M7.8 earthquake of Gorkha Nepal 2015 partially ruptured, at depth, the Main Himalayan Thrust (MHT), the great intercontinental thrust that separates the India plate from the Himalayas. Numerous paleoseismological trenches were excavated following the earthquake along the Main Frontal thrust, the surface expression of the MHT, in order to better understand the history of the very large earthquakes which produced total ruptures of the thrust system. Despite these efforts, the lateral extension of surface ruptures from regional historic or paleohistoric earthquakes (11th century, 1255, 1344 and 1934) is still widely debated, remaining uncertain. These uncertainties have a significant impact on the estimation of the seismic moment budget and on the determination of the regional seismic hazard.

To reduce them, we excavated some new paleoseismological sites. These excavations reveal a wide variety of expressions of the surface rupture and its geomorphological signature. These variations are controlled by the geometry of subsurface geological structures, but also by the ability of rivers to incise, aggrade and preserve outcrops.
Confronted with the previous trenches, these recent works make it possible to better specify the lateral extension of the strong earthquakes of 1934 and 1255 and their associated surface expression and characteristics.

Keywords: Himalaya, Main Frontal Thrust, Historical earthquakes

*Speaker

Source parameters and locations of the 1949 Mw7.4 Khait and 1907 Mw7.6 Karatag earthquakes: implications for how mountain ranges collide

Ben Johnson *[1], Galina Kulikova [2], Eric Bergman [3], Frank Krueger [4], Ian Pierce [1], James Hollingsworth [5], Alex Copley [6], Mike Kendall [1], Richard Walker [1]

[1] University of Oxford, Earth Sciences – United Kingdom
[2] Physikalisch-Technische Bundesanstalt – Germany
[3] Global Seismological Services, 1900 19th St. Golden, Colorado 80401 – United States
[4] Institute of Earth- and Environmental Science, University of Potsdam, Karl-Liebknecht-Str. 24-25, 14476 Potsdam – Germany
[5] Université Grenoble Alpes, ISTerre, Grenoble – Université Grenoble Alpes – France
[6] University of Cambridge, Earth Sciences – United Kingdom

The Pamir and Tian Shan ranges are currently colliding at _˜1cm/yr due to the convergence of India and Eurasia. This convergence is thought to be accommodated primarily by the Vakhsh Thrust and sinistral Darvaz Fault based on GNSS and seismotectonic evidence.
Understanding the source parameters of the largest earthquakes in the Pamir is essential to test this model of convergence. The 1949 Mw7.4 Khait and 1907 Mw7.6 Karatag earthquakes are examples of such events in the north-western Pamir. The historical nature of these events means seismological and geodetic data are lacking. As such, their locations and source parameters have been very uncertain – preventing our understanding of how they fit into the tectonic model of the north-western Pamir.

Here we present calibrated earthquake relocations for the 1949 earthquake and focal mechanisms determined from digitised seismograms for the 1949 and 1907 earthquakes. We also present a catalog of precise relocations for moderate magnitude earthquakes from 1949 to the present in vicinity of the Vakhsh Thrust. Finally, we present earthquake surface rupture mapping from the Vakhsh Valley, determined from ultra-high resolution elevation models derived from satellite stereoimagery.
We find that the 1949 Khait earthquake did not occur on the Vakhsh Fault, as previously thought, but on an unmapped fault in the Tian Shan basement. However, 10-20m scarps observed on the south Vakhsh valley show this fault is capable of producing large earthquakes. This tells us the Pamir–Tian Shan convergence is distributed across several basement faults capable of producing large earthquakes. It also tells us that the largest earthquakes may occur on faults which may appear minor in the landscape, which has implications for seismic hazard in the region.

*Speaker

Keywords: historical, earthquake, khait, pamir, collision

Qualitative and quantitative assessment of a lake sensitivity to paleoseismic events in the NW Alps

Mathilde Banjan * [1], Christian Crouzet [2], Erwan Messager [3], Pierre Sabatier [3], Hervé Jomard [4], Ludmila Provost [5], Aurore Laurendeau [6]

[1] Université Savoie Mont Blanc – ISTerre lab., University Savoie Mont-Blanc - CNRS, Le Bourget-Du-Lac, France, Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – France
[2] ISTERRE – Univerité Savoie Mont Blanc, Université Grenoble Alpes, CNRS, IRD, Institut Gustave Eiffel – 73376 Le Bourget du Lac Cedex, France
[3] Environnements, Dynamiques et Territoires de la Montagne – Centre National de la Recherche Scientifique : UMR5204 / FRE 2641, Université Savoie Mont Blanc – France
[4] Institut de Radioprotection et de Sûreté Nucléaire – Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – France
[5] Institut de Radioprotection et de Sûreté Nucléaire – Ministère de l'Enseignement Supérieur et de la Recherche Scientifique, Ministère de l'écologie de l'Energie, du Développement durable et de l'Aménagement du territoire, Ministère de Défense, Ministère de l'Economie, des Finances et de l'Industrie, Ministère du Travail, de l'Emploi et de la Santé – France
[6] Institut de Radioprotection et de Sûreté Nucléaire – Ministère de l'écologie de l'Energie, du Développement durable et de l'Aménagement du territoire – France

Several postglacial lakes in the western Alps bear mass movement deposits. Some of them have been analysed and were evidenced as homogenites deposits related to seiche (oscillation of the water mass usually subsequent to an earthquake). New multiproxy data from Lake Aiguebelette sediments highlight the presence of 33 homogenites deposited during the Holocene. Precise depositional age ranges of such deposits were constrained through varves counting and age-depth modelling based on short-lived radionuclides, paleomagnetic data and radiocarbon ages. These results are supported by core-to-core correlations based on geochemical and magnetic data.
The historical homogenites occurrence is of similar age to the seismic events archived in the French catalog *(SISFRANCE)*. These events are compatible with the *epicentral intensity* vs. *epicentral distance to the lake* charts *(cf. Wilhelm et al. 2016)*. Based on these charts, Lake Aiguebelette seems sensitive to strong and distant seismic events, meaning that only this type of event seems to be archived in the sediments (such as epicentral intensity 9 events: 1920 CE in Tuscany (IT); 1855 CE in Valais (CH); 1356 CE in Bale (CH)).

This qualitative sensitivity assessment was completed with a quantitative one, based on Ground motion prediction equation (GMPE) models.
GMPE *(Akkar et al., 2014; Bindi et al., 2014)* were applied to the events compiled in the parametric seismic catalog *FCAT (Manchuel et al., 2018)*. This allowed the calculation of the *Pseudo-Spectral Acceleration* (PSA, in cm/s2). For low frequencies, PSA vs. *epicentral distance to the lake* (in km) charts highlight a tendency of high PSA for high Mw events distant to the

*Speaker

lake location. This suggests a higher sensitivity of Lake Aiguebelette to such seismic events. For a given GMPE and lake location, the frequency seems to be a determining parameter in the assessment of a lake sensitivity to seismic events.

Keywords: paleoseismicity, lacustrine, homogemite, GMPE, frequency, models

Did a 3,800 years old _˜Mw9.5 earthquake trigger major social disruption in the Atacama Desert?: Geoarchaeological evidence

Gabriel Easton *† [1], Et Al. [2]

[1] Geology Department, University of Chile – Chile
[2] Chile – Chile

Early inhabitants along the hyperarid coastal Atacama Desert in northern Chile developed resilience strategies over 12,000 years, allowing these communities to effectively adapt to this extreme environment, including the impact of giant earthquakes and tsunamis. Here, we provide geoarchaeological evidence revealing a major tsunamigenic earthquake that severely impacted prehistoric hunter-gatherer-fisher communities _˜3,800 years ago. Field evidence includes uplifted littoral deposits, distinctive paleotsunami deposits, unconformities, erosional features, stratigraphic changes in the content of cultural remains and change in the position of archaeological sites with respect to the modern coastline, recognized for at least 700 km. This caused an exceptional social disruption reflected in contemporary changes in archaeological sites triggering resilient strategies along these coasts. Together with tsunami modeling results, we suggest that this event resulted from a _˜1,000 km long megathrust rupture along the subduction contact of the Nazca and South American plates, highlighting the possibility of Mw _˜9.5 tsunamigenic earthquakes in northern Chile, one of the major seismic gaps of the planet. This emphasizes the necessity to account for long temporal scales to better understand the variability, social effects, and human responses favouring resilience to socio-natural disasters.

Keywords: Tsunami, archeoseismicity, Chile

*Speaker
†Corresponding author: geaston@uchile.cl

Re-evaluating the 1948 Ashgabat earthquake, Turkmenistan. Evidence for a multi-fault rupture?

Neill Marshall Et Al. *† [1]

[1] University of Oxford – United Kingdom

The 1948 M 7.3 Ashgabat earthquake, killing over 38,000 people, occurred in the dextral strike-slip Kopeh Dagh fault zone in the Iran-Turkmenistan border region. Previously, it has been debated which fault(s) it occurred on and whether this earthquake was a thrust/reverse, strike-slip, or multi-fault earthquake, as published focal mechanisms suggest it had a reverse mechanism. We relocated the hypocentre using historical seismograms and present a new strike-slip focal mechanism. We use Pleiades tri-stereo and WorldView3 satellite imagery to produce Digital Elevation Models of part of the ruptured area. The data reveals clear strike-slip faults where surface ruptures were mapped in 1948. The earthquake did not rupture the Main Kopeh Dagh fault, but instead multiple subsidiary faults, highlighting the importance of considering lesser faults in seismic hazard models.

Keywords: Caucasus, Kopeh Dagh Fault, historical earthquake

*Speaker

†Corresponding author: neill.marshall@worc.ox.ac.uk

From stratigraphic analysis to Finite Element models in the archaeoseismic study of the Ronta bell tower

Arnaud Montabert *† [1], David Gomez Diaz [1], Cédric Givry [1]

[1] Ecole Normale Supérieure Paris-Saclay – Université Paris-Saclay,Sorbonne Universités – France

Archaeoseismology highlights past earthquakes' effects by analyzing traces recorded in man-made structures. Among these, historical buildings like bell towers witnessed earthquakes recorded in their walls as structural disorders, repairs, and restorations. We question the sensitivity of the structure's dynamic characteristics to this complex constructive history to understand whether this information should be considered when designing digital models. In the context of the research project ANR-ACROSS, we studied four bell towers that suffered damage for at least one strong earthquake during medieval times. This work defines a methodology to include the stratigraphic analysis in the modeling process of an ancient masonry bell towers. The methodology is illustrated with the Ronta bell tower case study (Italy, Tuscany). Building techniques are first identified and recorded in a dedicated database. Procedures are implemented to extract the contours of constructive phases. Building phases' geometry and material properties are projected in a Finite Element mesh. The first results show a frequency shift when including the constructive history.

Keywords: Historical earthquake, Damage, Finite Element Modelling, Northern Italy

*Speaker
†Corresponding author: arnaud.montabert@ens-paris-saclay.fr

Advances and Challenges in Quaternary Geochronology

Climate and tectonic forcings driving the coastal landscape evolution: clues form late quaternary fan lobes in Kachchh region (NW India)

Eshaan Srivastava *† [1], Nicolò Parrino [2], Javed Malik [1], Pierfrancesco Burrato [3], Cipriano Di Maggio [2], Mahendrasinh Gadhavi [4], Nayan Sharma [1], Attilio Sulli [2]

[1] Indian Institute of Technology Kanpur, Earth Sciences – India
[2] Dipartimento di Scienze della Terra e del Mare, Università degli studi di Palermo, Palermo – Italy
[3] Istituto Nazionale di Geofisica e Vulcanologia, Rome – Italy
[4] Civil Engineering Department, L. D. College of Engineering, Ahmedabad – India

160 km long hill ranges in the Kachchh region (NW-India) form a major E-W oriented topographic break delimiting the marshy plain of Banni in the North from the more elevated area of the Katrol Hill Range (KHR) in the south. Such topographic break is considered as the superficial expression of a quaternary active fault labelled Kachchh Mainland Fault (KMF). Numerous rivers cross this hilly region flowing roughly from South to North. The majority of those rivers are characterized by extensive fan lobes pinching out from the 200–300-meter anticlines of the hilly range.
Starting from archaeological evidence from the past 4000-5000 years, it has been inferred that an extremely fast coastal landscape evolution brought such a region to evolve from an initial gulf landform to the current setting, i.e., the marshy plains of Banni and the salt-encrusted Rann. The location of the fans lobes marked the boundary between the fluvial and marine environments.

High sedimentation rates varying between 1.1-2 mm/yr reported for the Banni plains, together with historical and recent earthquakes (1668 Indus Delta, 1819 Allah Bund, 1845 Lakhpat, 1956 Anjar and 2001 Bhuj), provide valuable constraints for inferring the climatic and tectonic forcing on the region's quick dynamics.
In our ongoing work, we propose a multidisciplinary approach made by morphotectonic mapping, morphometric analyses, and geochronology to understand better how the interplay of tectonics and eustatic perturbations drove such an abrupt landscape evolution.

Keywords: Landscape Evolution, Alluvial Fans, Luminescence Dating

*Speaker
†Corresponding author: eshaan@iitk.ac.in

Morphotectonic evaluation and Paleoseismic studies of the Himalayan frontal belt bounded by the Main Boundary Thrust (MBT) and Himalayan Frontal Thrust (HFT), Kumaun Central Himalaya

Mitthu Dhali * [1], Javed Malik [1], Eshaan Srivastava [1], Nayan Sharma [1], Gurvinder Singh [2]

[1] Indian Institute of Technology Kanpur – India
[2] Punjab University, Chandigarh – India

The Himalaya is one of the world's most seismically active mountain belts, accumulating strain during the interseismic period and releasing it as earthquakes. In the last century only, it has been the locus of some of the largest continental earthquakes of the world 1905 Kangra earthquake (Mw 7.8), 1934 Bihar-Nepal earthquake (Mw 8.1), 1950 Assam earthquake (Mw 8.4), 2005 Muzaffarabad earthquake (Mw 7.6) and 2015 Gorkha earthquake (Mw 7.8). The plate convergence between India and Eurasia is accommodating predominately along the Main Himalayan Thrust (MHT). The foreland basin bounded by the MBT and HFT is the present-day active wedge of the Himalayas. Paleoseismological, Geological, and Geodetic data of the last two decades all along the Himalayan arc have been suggesting that greater Himalayan earthquakes have ruptured the frontal part in recent as well as in medieval times. With the recorded history of earthquakes, the Central Seismic Gap (CSG) has experienced several large as well as great earthquakes in medieval times. The most recent great earthquake in Central Himalayas occurred in AD 1505, with a magnitude of 8.2 Mw since then the area has been accumulating strain at a rate of 15- 20 mm/yr, accumulated 10 m of slip deficit, capable of generating several Mw 8 earthquakes. It is been very important to understand the seismic scenario of the region in terms of its spatial and temporal distribution of the past earthquakes and the behavior of the faults. There exist large uncertainties to determine the most recent surface rupturing event in the Central Himalaya. In the absence of a well-constrained historical record of the timing, location, and magnitude of past earthquakes more focus should be made on the geomorphological and paleoseismological investigation to determine the ongoing tectonic activity.

Keywords: Active Tectonics and Paleoseismology

*Speaker

Luminescence dating of the dammed lake formed by the catastrophic Beshkiol landslide along the Naryn River (Tien Shan)

Julie Losen * [1], Magali Rizza† [1], Lionel Siame‡ [1], Maxime Henriquet§ [1], Alexis Nutz¶ [1], Jules Fleury‖ [1], Ian Pierce** [2], Erkin Rakhmedinov†† [3]

[1] CEREGE – Aix Marseille Université (Aix-en-Provence) – France
[2] Department of Earth Sciences, University of Oxford – United Kingdom
[3] Institute of Seismology, National Academy of Sciences of the Kyrgyz Republic – Kyrgyzstan

Our study is located in Kyrgyzstan along the Naryn River in the Tien Shan range, where earthquakes and landslides are major risks to societies and economies.
Along the Naryn River, previous works have shown that the Beshkiol mega-landslide (10 km-long, 7 km-wide) has been responsible for damming the river in the past. This landslide is poorly accessible and for this reason, its age is poorly constrained. Thanks to the analysis of Pleiades satellite and drone images and associated DEMs, we propose a detailed mapping of the basin with numerous fluvial deposits as well as paleo-shorelines of ancient lakes preserved upstream of this landslide. The geomorphological mapping and the stratigraphic sections observed in the field show at least two major damming episodes. These sedimentary records are the unique way to constrain the age of the landslide activation.

To date the age of lake sediments, we performed luminescence (OSL) and 14C dating methods on some sedimentary units spread throughout the basin. The combination of the different dating methods allow us to propose that the last high lake level occurred at ˜10 ka and lasted for at least 20 ka. This lake could have had an extension 100m above the current base level of the river, 58 km-long and 10 km-wide during this phase. The lake sediments are now perched 110m above the Naryn river, indicating a rapid emptying of the lake.
All these observations are intended to be placed in the regional geological context in order to understand the geomorphological evolution of the Naryn Basin and to document major changes in its sedimentary dynamics that may be related to climatic or tectonic factors.

Keywords: luminescence, landslide, paleolake, Tien Shan

*Speaker
†Corresponding author:
‡Corresponding author:
§Corresponding author:
¶Corresponding author:
‖Corresponding author:
**Corresponding author:
††Corresponding author:

Combining ESR and 10Be dating of fluvial terraces of the Santo Domingo River on the Southeastern of Mérida Andes, Venezuela: Methodology and tectonic implications.

Oswaldo Guzman * [1], Marisel Díaz [2], Riccardo Vassallo [3], Franck Audemard [4], Aleida Gonzalez [2], Jean-Louis Mugnier [5], Corina Campos [1]

[1] Grupo de Ciencias de La Tierra y Clima. Universidad Regional Amazónica Ikiam, Ecuador – Ecuador
[2] Instituto Venezolano de Investigaciones Científicas – IVIC, Centro de Física-Laboratorio de Materia Condensada, 1020-A, Altos de Pipe, Venezuela – Venezuela
[3] ISTerre – Université de Savoie Mont-Blanc, 73370, Bourget du Lac, France – Université de Savoie Mont Blanc, CNRS-UMR5204, Campus scientifique, Bâtiment Pôle Montagne , 73376, Le Bourget du Lac, France – France
[4] Departamento de Ciencias de la Tierra e Fundacion Venezolana de Investigaciones Sismológicas, Caracas, Venezuela – Venezuela
[5] CNRS - ISTerre, Université de Savoie Mont-Blanc, CNRS, F-73376 Le Bourget du Lac, France – Centre national de la recherche scientifique - CNRS (France) – France

In this study we discuss the first ESR dating of river terraces located in the middle and lower reaches of the Santo Domingo river (Southeastern flank of the Mérida Andes, Western Venezuela). ESR ages were compared and combined with previously performed 10Be ages and integrated with sedimentologic and geomorphic observations allowed the restoration of the temporal evolution of incision rate, which was analyzed in terms of tectonic, climatic and geomorphic processes. Our results show that in materials deposited under stable conditions involving long-term sediment transport processes, the ESR and 10 Be ages tend to be similar. While in rapidly deposited materials, the ESR ages tend to be overestimated, highlighting the importance of selecting the appropriate material for each type of dating. On the other hand, the ages that converge allow us to estimate that the long-term incision rate in the area has been constantly around 1 mm/a over the last 70 ka. Taking into account the geological and geomorphologic setting, this value can be converted into the Late Pleistocene uplift rate of the Southeastern flank of the Mérida Andes.

Keywords: ESR, 10Be, river terraces, uplift rate, Mérida Andes, Venezuela

*Speaker

Inheritance of Detrital Charcoal: Implications for Age Estimates on Paleoearthquakes

Thomas Rockwell * [1], Aron Meltzner [2]

[1] San Diego State University – United States
[2] Nanyang Technological University – Singapore

We compiled two independent radiocarbon datasets from stratigraphic sequences in southern California in an attempt to determine the extent to which detrital charcoal is either reworked or carries inherited age. In the first dataset, we combine 296 stratigraphically constrained radiocarbon dates from Lake Cahuilla (Rockwell et al., 2022) with 95 dates from a new study at Salt Creek, also from Lake Cahuilla, and show that nearly half of all dates are older than underlying strata, indicating significant age inheritance. The second dataset, from Hog Lake (Rockwell et al., 2015), contains 111 dates, many of which were dates on seeds contained in thin organic mat layers. In the Hog Lake dataset, only _˜24% of dates exhibit ages older than underlying strata, but all of the seeds were in stratigraphic order, suggesting that chronologies constructed from single-year growth samples substantially improve the accuracy of the ages of individual strata. The percentage of reworked or older charcoal indicates that paleoseismic studies should consider dating twice as many samples as are expected to define an age sequence. Further, whenever possible, single-year growth samples, such as seeds and pine cones, should be dated to help constrain and anchor a chronologic model. These statistics have broad implications not only for paleoseismic studies, but for fire frequency and slip rate studies. Importantly, reliance on a single date to quantify processes or events is problematic.

Keywords: Detrital charcoal, inheritance, dating paleoearthquakes

*Speaker

Quaternary faults reactivation in the Northern Calcareous Alps (Austria): kinematics and timing inferred from caves passage offsets

Jacek Szczygieł * [1,2], Ivo Baroň [3], Rostislav Melichar [4], Lukas Plan [5], Bernhard Grasemann [2], Mitrović-Woodel Ivanka [2], Kamimsky Eva [6], Denis Scholz [7]

[1] Institute of Earth Sciences, University of Silesia in Katowice – Poland
[2] Department of Geology, University of Vienna – Austria
[3] Institute of Rock Structure and Mechanics, The Czech Academy of Sciences – Czech Republic
[4] Department of Geological Sciences, Masaryk University – Czech Republic
[5] Karst and Cave Group, Natural History Museum – Austria
[6] Institute for Soil Physics and Rural Water Management, University of Life Sciences BOKU – Austria
[7] Institute for Geosciences, Johannes Gutenberg University Mainz – Germany

The Northern Calcareous Alps (NCA) are dissected by strike-slip faults, which accommodate the N-S shortening and E-W stretching of the orogen. However, the timing of the fault activation is poorly constrained by absolute dating or faulting of Neogene deposits. Hence there is a knowledge gap in the Post-Miocene tectonic evolution, which is also due to the geomorphic signal caused by fault movement has been destroyed by glaciations. Fortunately, karst caves may serve as the geomorphic displacement indicators and provide timing constraints via U-Th dating of broken speleothems. We documented 172 reactivated faults in 28 caves adjacent to major faults; some were dated with the 230Th/U method. Using the inversion method, we computed the paleostress.

We recorded extensional relay along Königsee-Lammertal-Traunsee Fault in Göll and Hagengebirge, while in Tennegebirge we recorded dextral shear along Lammertal fault. In Dachstein, the faults orientation and reverse sense indicate N-S shortening. Further to the East, NNE compression in relation to the Salzach-Ennstal-Mariazell-Puchberg fault (in Totes Gebirge and Hochschwab), as well as Mur-Mürz Fault, caused sinistral shearing along them. The extension along the Vienna Basin margins is consistent with the pull-apart basin opening mode along the Vienna Basin Transfer Fault. These changes in the compression trends between major faults segments are consistent with the general trend in the Eastern Alps. The western segment of NCA, N of Tauren Window, aligns in the convergence axis, so N-S shortening dominates. The further East, the stronger the influence of the extruded main wedge, thus the compression towards the NE.

Our results indicate that NCA has been subjected to the N to NE trended compression since Middle Pleistocene, as pointed by U-Th dating, and possibly since Pliocene, as inferred from the maximum caves age. Thus, we confirm the dominance of Post-Miocene lateral extrusion over gravitational collapse with the geological record.

*Speaker

Keywords: neotectonics, fault reactivation, U, Th dating, paleostress, Alps

Constraint of Quaternary fault activity using quartz OSL and detrital zircon U-Pb ages

Tae-Ho Lee * [1], Jin-Hyuck Choi† [1], Youngbeom Cheon [1], Shinae Lee [2]

[1] Korea Institute of Geoscience and Mineral Resources – South Korea
[2] Korea Basic Science Institute – South Korea

In paleoseismology, age determination is used as an important means to constrain the recurrence intervals and timing of fault activities. Representative means of age determination mainly used in paleoseismic studies include radiocarbon, cosmogenic nuclides, and OSL. These techniques are usefully utilized to acquire temporal information about paleoearthquakes, but have a limitation that can not constrain the direct timing of fault activity. In other words, only the indirect timing of fault movement can be suggested by identifying the depositional age of the sedimentary layer affected by the fault. In this study, we conducted additional OSL analysis to determine detailed sedimentation records at the Inbo trench excavation located in the Yangsan Fault System in the Korean peninsula reported by Cheon et al. (2020). In addition, we inferred the direct timing of fault movement using detrital zircon U-Pb age.
The study area consists of four unconsolidated units (unit-4 to 1 from the bottom), and the depositional ages by OSL are long before 70 ka for unit-4, at ca. 70 ka for unit-3 to –2, and from ca. 70 ka to after 29 ka for unit-1. In this area, at least three fault movements were identified, and OSL ages suggested that the MRE and PE occurred after 29 ka and ca. 70 to 50 ka, respectively. Sediment provenances changed twice dramatically during an extremely short period when unit-4, 3, and 1 were simultaneously deposited, which is presumably due to the paleoearthquakes. Therefore, it can be inferred that fault activities occurred twice at about 70 ka. This study suggests the possibility that the provenance study can be effectively used to limit the timing of fault movement.

Cheon, Y. et al., 2020, Late Quaternary transpressional earthquakes on a long-lived intraplate fault: A case study of the Southern Yangsan Fault, SE Korea. Quaternary International, 553, 132-143.

Keywords: OSL, detrital zircon, U, Pb, timing of fault movement

*Speaker
†Corresponding author: cjh9521@kigam.re.kr

Luminescence and ESR dating for palaeoseismology and active tectonics : limits and future possibilities

Sumiko Tsukamoto * [1]

[1] Leibniz Institute for Applied Geophysics – Germany

Luminescence and electron spin resonance (ESR) dating methods utilise the detection of trapped charge in quartz and feldspar, and have ultralow closure temperatures. For applications in palaeoseismology and active tectonics studies, luminescence dating has been used e.g. to estimate the timing of past earthquakes in trench excavations or to calculate slip rates of faults by dating deformed Quaternary surfaces. However, the luminescence signal of quartz and feldspar typically reaches to saturation at ~50 and ~300 ka, respectively, limiting the applicable age range.

An alternative material, which can be used for luminescence and ESR dating, is the fault gouge. Direct dating of fault gouges has the potential to estimate past activity of faults, even if there is no other information available from deformed sediments and topography. Previous attempts of dating fault gouges from active faults confirmed that the signals were reset, at least partially, by past earthquakes. However, when ages were compared with the timing of known large earthquakes, they were, in most cases, significantly overestimated, suggesting it is likely that the signals were not fully reset by a single earthquake.

In this presentation, I introduce a new feldspar dating protocol using a multiple aliquot approach, which can significantly extend the age range of luminescence dating up to ~600 ka. A new method for evaluating fault activity using fault gouge dating is also introduced, based on the assumption that periodical large earthquakes partially reset the luminescence and ESR signals.

Keywords: luminescence dating, ESR dating, sediments, faults, Quaternary

*Speaker

Episodic deformation in the western Transverse Ranges of California during the past 125 kyr

Nate Onderdonk * [1], Clay Kelty [2], Ian Mcgregor [3]

[1] California State University Long Beach – United States
[2] Earth Consultants International – United States
[3] Lettis and Associates – United States

The western Transverse Ranges of California is an active fold and thrust belt with high rates of shortening (7 to 12 mm/yr) and rock uplift (up to 7 mm/yr). We used late Quaternary fluvial and marine terraces as markers to measure deformation rates across the major faults in the inverted Santa Maria Basin that makes up the northwestern part of the mountain belt. Mapping, surveying, and luminescence dating of multiple terrace levels show that rock uplift rates and fault slip rates have changed along some of the major faults over the past 125 kyr. Between 125 ka and 85 ka, a fluvial unit (the Orcutt Formation) was deposited on a low-relief peneplain that extended across most of the Santa Maria Basin. The faults that cross the area were not actively deforming the surface at the time. Around 85 ka, multiple reverse faults began to lift and deform the Orcutt Formation with uplift rates of 2 to 5 mm/yr in the hanging walls of the faults. This uplift decreased after 60 ka, and terraces younger than about 35 ka are undeformed across some of the faults.
Stratigraphic and structural data indicate that these faults developed as early as middle Miocene time and experienced significant pre-Quaternary displacement. Therefore, the late Quaternary episodes of quiescence and deformation suggest these faults may have experienced multiple cycles of activity and inactivity over millions of years. Such variable deformation rates through time would make active fault hazard assessment in the region difficult. Although there is little evidence of Holocene displacement across these faults, the long-term temporal patterns suggest they have the potential to become active again.

Keywords: California, faults, fluvial terraces, fold, and, thrust, uplift

*Speaker

A new long-term slip-rate on the Banning Fault to help untangle the deformation pattern of southern California

Anne-Sophie Mériaux *† [1], Matilda Nash [2], Jerome Van Der Woerd [1], Rick Ryerson [3]

[1] Institut Terre et Environnement de Strasbourg ITES UMR7063 – Université de Strasbourg, CNRS, ENGEES – France
[2] School of GPS, Newcastle University – United Kingdom
[3] LLNL – United States

Southern California accommodates most of the Pacific-North America plate motion, partitioned within a regional complex network of active faults, aside the San Andreas Fault (SAF). East of San Gorgonio Pass, the segmentation in the Coachella Valley is particularly puzzling with an enduring debate about the identification of the main strand of the SAF. Here, we investigate the Banning Fault (BF) to establish a long-term slip-rate to enhance our understanding of the slip partitioning. Morphological mapping of the alluvial fan sequences helps define a right-lateral offset of 342 ± 56 m of the most prominent surface observed and dated at the study sites. To constrain the rate, numerous quartz-rich samples, collected from both surfaces and depth profiles on alluvial surfaces, were processed for Cosmogenic Radionuclide (CRN) isotope dating. The CRN data help to constrain the ages and the landscape evolution of this dynamic bajada, and to estimate a long-term slip rate of 13.2 ± 2.5 mm/yr on the Banning Fault over the last 33 ka. This new slip-rate implies that the Banning Fault has the potential to propagate ruptures across the San Gorgonio restraining bend. This new BF rate should help review the deformation and kinematic models focusing on Southern California over a longer time period by first and foremost updating the late-Holocene BF rate of 4 mm/yr used in the current models, which underestimate this major fault strand in the complex slip-partitioned San Andreas fault system.

Keywords: Southern California, rate, CRN dating

*Speaker
†Corresponding author: anne-sophie.meriaux@unistra.fr

Assumptions and limitations in interpreting 10Be and 26Al cosmogenic isotope surface and sub-surface data

Jerome Van Der Woerd *† [1], Anne-Sophie Meriaux [1]

[1] Institut Terre et Environnement de Strasbourg ITES UMR7063 – Université de Strasbourg, CNRS, ENGEES – France

Dating soils, fans, terraces or moraines with cosmogenic nuclides implicitly assumes the knowledge of a certain number of parameters. Using cosmogenic radionuclide (CRN) depth profiles help the dating effort, yet these are notoriously challenging to interpret given the number of unknown variables to constrain simultaneously (time, erosion/sedimentation, pre-exposition, density, ...). While some of them can be calculated, reasonably assumed or guessed, their determination or indetermination allows for various interpretations. Our goal is to discuss commonly made assumptions on these parameters, and in particular on the inheritance distribution among surface and sub-surface samples, possible erosion rate variations with time, density estimates and some ways to better constrain them. We will take well-documented examples from the literature allowing that discussion, i.e. both surface and sub-surface data from the same geomorphic features are analyzed, cosmogenic nuclide data are combined with other dating methods, multiple surfaces are analyzed, numerous samples allow to assess statically the nuclide distributions and model ages. In many cases, independent knowledge from other methods is necessary to unravel the complex exposure histories of the investigated geomorphic features and associated samples.

Keywords: 10Be, inheritance, erosion, nuclide distribution, model ages

*Speaker

†Corresponding author: jerome.vanderwoerd@unistra.fr

Late Pleistocene and Holocene paleoseismology and deformation rates of the Pleasant Valley Fault (Nevada, USA)

Paula Figueiredo *† [1], Steven G. Wesnousky [2], Lewis A. Owen [1]

[1] Department of Marine, Earth, and Atmospheric Sciences [NCSU] – United States
[2] Center for Neotectonic Studies and Nevada Seismological Laboratory, University of Nevada, Reno, Nevada – United States

The Pleasant Valley Fault (PVF) is the northernmost active fault in the Central Nevada Seismic Belt (CNSB), an area of increased seismic activity within the Basin and Range that southwards merges into the Walker Lane. On October 2nd 1915, PVF generated a magnitude 7.3 earthquake, producing scarps with an average displacement of 2m (maximum 5.8 m) along a rupture _˜60 km long. This earthquake was the first of a CNSB seismic sequence of similar magnitudes, including the 1932 Cedar Mountain and 2 earthquakes in 1954 Dixie Valley - Fairview Peak and Fallon Stillwater. The PVF system displaces alluvial fans along the western Tobin Range mountain front, and cumulative Quaternary displacement is recognized through older scarps. The 1915 rupture had four segments and the two central Pearce and Tobin segments exhibit the highest and largest scarps. We excavated five new paleoseismic trenches across the 1915 ruptures, at 4 locations in the two central segments. Colluvial stratigraphy exposed in the trenches records multi-event earthquake histories at each site. The colluvial units are generally fine gravel to sandy sediments and in addition a tephra layer is present at one trench. The colluvial sequence and the displaced alluvial fan, present different degrees of pedogenic development, and occasionally carbonate enriched. To constrain the paleoseismology, preliminary 25 luminescence ages on quartz and k-feldspar and one tephrochronology age on the colluvial units tentatively provide evidence of 3 or 4 events pre-1915 during the last _˜45 ka. To estimate the ages of the alluvial fans and calculate long term deformation rates associated to the fault system and mountain front development, we sampled boulders (when available) and sediment for depths profiles for terrestrial cosmogenic nuclide dating (10Be and/or 36Cl), at 6 sites placed along the mountain front at relative different positions of the fans and fault system.

Keywords: Intra, continental seismicity, Central Nevada Seismic Belt, paleoseismicity, Geochronology

*Speaker
†Corresponding author: paula_figueiredo@ncsu.edu

2022 updates regarding slip rates along Patagonia's fastest slipping strike strip faults: the Magallanes Fault (MF) and Liquiñe-Ofqui fault zone (LOFZ)

Gregory De Pascale Et Al. *† [1]

[1] University of Chile – Chile

Prior to 2020, slip rates along the LOFZ and the MFS in Chile and Argentina were unknown. Along the LOFZ, studies by De Pascale et al. 2021 and Astuidillo et al. 2021 at sites $>$ 600 km apart yielded consistent Quaternary slip rates of 11.6–24.6 mm/yr and 18.8$\pm$2.0 mm/yr respectively. An unpublished airborne lidar dataset collected to evaluate the southernmost LOFZ revealed clear strike slip and vertical displacements under the rainforest near Laguna San Rafael, Chile.
The displacements when combined with the ample Quaternary dating provides high-resolution vertical _˜7 $\pm$ 2 mm/yr and dextral slip rates _˜14 $\pm$ 4 mm/yr. These results are higher resolution and validate the De Pascale et al. 2021 estimates and provide direct insight to Late Quaternary LOFZ behaviour. Moving southwards, along the MFS, recent work by Roy et
$> >$ al. 2020 and Sandoval and De Pascale (2020) revealed left lateral slip rates for the first time in Chile. The Sandoval and De Pascale work addressed sites the Hope, Deseado, and Magallanes Fault (MF) with MF slip rates of 7.8$\pm$1.1mm/yr (Chile) and 7.8$\pm$1.3 mm/yr (Argentina).
The Roy et al., 2020 work focused on Argentina and obtained slip rates of 6.4 $\pm$ 0.9 mm/yr using displacements mixed with cosmogenic dating. The overlap in values from these two studies show self-consistency. Ongoing follow-up work using a number of onshore and offshore methods (MBES, SBP, UAV) are helping to mapping fault locations, improved slip rates, and evaluate width of deformation at the surface and help provide insight into the regional seismic hazard and neotectonics.

Keywords: Active fault, Chile

*Speaker

†Corresponding author: snowyknight@gmail.com

Advances in earthquake geology techniques

First paleosismology analysis in Ecuadorian Amazon piedmont: implication for seismic risk analysis.

Carolina Cornejo * [1], Oswaldo Guzman [2], Corina Campos [2], Dennys Chalco — [1], Cristian Cargua [1]

[1] Universidad Regional Amazónica IKIAM – Ecuador
[2] Grupo de Ciencias de la Tierra y Clima. Universidad Regional Amazóni Ikiam – Ecuador

Analysis of paleoseismology and its application in the Ecuadorian Amazon, as far as is known, has not been carried out. This technique has been used most frequently in the Sierra region of Ecuador analyzing major faults. However, instrumental and historical seismicity has shown that earthquakes of magnitude 6 and 7 can occur, such as those that occurred in 1987 (IGE, 2012), in Ecuadorian Amazon. In this region, the analysis of faults is essential because their occurrence could affect oil ducts, which act as a hydrocarbon artery, causing severe structural damage, economic losses, and environmental impacts. Therefore, in the present research work, the paleoseismology of a surface fault possibly associated to the Napo seismogenic source was analyzed. The analysis was carried out in a trench of 14 m x 3.5 m. The main stratigraphic units were identified and analyzed in order to determine the vertical component of the fault displacement, the seismogenic sediment deformation and to estimate the paleo-magnitudes earthquakes associates. The results showed that there were at least three seismic events, one with a magnitude of 6.5 and two with magnitudes around 6. In addition, the identification and characterization of the seismites presents in the predominantly fine-grained sedimentary deposits (e.g. ball and pillow, boudinage, fluid escape, among other) allow us to interpret a seismicity with a range of magnitudes that varies between 6 and 7. The data obtained show that the faults present in the Amazonian piedmont they should be considered for seismic risk analysis.

Keywords: Paleoseismology, Ecuadorian Amazon, seismites, Napo seismogenic

*Speaker

Numerical 3D back-slip reconstructions from high-resolution imagery of Western Alps active faults

Riccardo Vassallo * [1], Anne-Clothilde Legal [2], Hervé Jomard [3], Jean-Louis Mugnier [4], Christophe Larroque [5], Christian Sue [6], Pierre Assali [7]

[1] Institut des Sciences de la Terre (ISTerre) – Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS : UMR5275 – BP 53 - 38041 Grenoble cedex 9, France
[2] Institut des Sciences de la Terre (ISTERRE) – Université Savoie Mont Blanc, Université Grenoble Alpes, CNRS, IRD, IFFSTAR, ISTERRE, Chambéry – France
[3] Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – BP17 92262 Fontenay-aux-Roses Cedex, France
[4] Institut des sciences de la Terre (ISTerre) – CNRS : UMR5275, IFSTTAR, IFSTTAR-GERS, Université de Savoie, Université Joseph Fourier - Grenoble I, INSU, OSUG, Institut de recherche pour le développement [IRD] : UR219, PRES Université de Grenoble – BP 53 38041 Grenoble cedex 9, France
[5] Géoazur (GEOAZUR) – Université de Reims - Champagne Ardenne – Bât 1, 250 rue Albert Einstein Les Lucioles 1, Sophia Antipolis 06560 VALBONNE, France
[6] ISTerre – Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS, IRD, IFSTTAR, ISTerre, 38000 Grenoble, France – France
[7] Altametris - filiale de SNCF Réseau, Lyon, France – Altametris : Altametris- filiale de SNCF Réseau, Lyon, France – France

The low rates of tectonic deformation in the Western Alps make it difficult to detect active faults and to identify and quantify the processes causing seismicity. The instrumental and historical seismicity record, although valuable to individualize seismogenic sources, is not sufficient to provide accurate information concerning their long-term seismic activity. GPS data acquired over the last 20 years show horizontal velocities that are most often too slow to accurately constrain the kinematic and slip rate of individual faults.
The millennial action of tectonic deformation can however be observed through the formation of characteristic morphologies, especially on mountain slopes rejuvenated by glaciers erosion during the last glacial period. Multi-metric fault scarps affecting glacial landforms could be observed on the Remuaz fault in the Aiguilles Rouges massif and along the Bersezio fault in the Argentera-Mercantour massif. These strike-slip faults are seismically active and have geological lengths of several tens of kilometers, making of them potential major seismogenic sources in the region. In this context, the integration of the deformation process at the millennial scale is the key to have a signal that spans several seismic cycles and whose amplitude may be quantified.
Using satellite imagery and fieldwork we selected and mapped the most suitable sites along these structures characterized by geomorphic markers displaced by faults. We then obtained digital elevation models by Structure from Motion from unmanned aerial vehicle and by LiDAR techniques. We numerically cut these models and performed back-slip restorations using Cloud Compare software in order to reconstruct pre-deformation geometries. This analysis allowed us to retrieve the fault kinematics and the cumulate deformation during the post-glacial period.

*Speaker

The results of this work will implement the database of the French active faults to improve the seismic hazard assessment.

Keywords: Alps, imagery, digital elevation models, faults

Analysis of geomorphological index for the characterization of the neotectonic activity of the Tena Fault in the Amazon foothills

Belén Benites * [1], Oswaldo Guzman [2], Corina Campos [2]

[1] Universidad Regional Amazónica Ikiam. Ingeniería en Geociencias – Ecuador
[2] Grupo de Ciencias de La Tierra y Clima. Universidad Regional Amazónica Ikiam. Ingeniería en Geociencias. – Ecuador

The objective of this work is to apply, for the first time, geomorphological index (mountain front sinuosity, basin shape index, Hack index and drainage basin asymmetry factor) to analyze the tectonic activity of the Amazonian piedmont in Ecuador. The analysis was performed on a 18.50 km segment of the Tena surface fault. First of all, the trace of the fault was mapped in detail from morphotectonic evidence (rectilinear drainage, displaced drainage, trapezoidal facets). Subsequently, the geomorphological index were calculated in a GIS environment. The quantitative results obtained show that: i) in the northern part there is greater deformation, which is also observable in the path of the fault trace, which changes from north-south to south-east, from the north to the south, ii) the studied area is exposed to high to moderate tectonic activity, which is highlighted by the correlation between the four calculated geomorphological index. Finally, the results obtained validate the usefulness of this technique to highlight tectonic activity in the Amazonian foothills of Ecuador, where tropical weathering processes and high vegetation cover complicate conventional qualitative analysis.

Keywords: Geomorphologic index, active tectonic, Amazon piedmont, seismic hazard, Ecuador

*Speaker

Introduction to the mapping and quantitative analysis of surface ruptures using deep learning and satellite

Yire Choi * [1], Jin-Hyuck Choi [1], Yeonju Choi [2]

[1] Korea Institute of Geoscience and Mineral Resources – South Korea
[2] Korea Aerospace Research Institute – South Korea

Large-scale detailed mapping of earthquake-induced surface ruptures is an important task that is fundamental to elucidating the geological structure and characteristics and mechanisms of earthquake ruptures, but it requires a lot of time and effort to achieve this including both human and material. Methods for detecting and analyzing cracks in concrete, bridges, roads, or buildings based on deep learning are being actively studied and utilized in various fields. However, in the field of Earthquake geology and Paleoseismology, there are relatively few or non-existent cases where it is applied to and utilized in the study of surface ruptures that occurred by the earthquake. Pixel-level surface rupture detection can provide more intuitive and accurate detection results for evaluating geological structures and earthquake rupture characteristics and mechanisms. Therefore, to implement pixel-level crack detection, this study proposes a method for detecting surface ruptures in a wide area using deep learning and high-resolution satellite imagery (Pleiades 1B) and extracting quantitative information. To verify the performance of the proposed network model, the detected results are compared with previous research data. The overall model reliability is achieved by achieving surface rupture detection precision of about 85% or more and extraction characteristic information level within an error level of 5% or less. Through this, the excellent performance of the network model was verified and it is suggested that it can be used as an objective and efficient tool for detecting and analyzing surface ruptures distributed in a wide area due to earthquakes.

Keywords: Surface rupture detection, Deep learning, Convolutional Neural Network, Remote sensing

*Speaker

High-Resolution multichannel seismic reflection experiment with active tectonics objectives: Defining the deep geometry of the faults bounding the Guadalentin Depression (SE Iberia)

Hector Perea *† [1,2], Paula Herrero Barbero [1], Júlia Molins Vigatà [1], Juan Alcalde [3], José Antonio Álvarez Gómez [1], María Berriolópez Llamosas [1], Ramon Carbonell [3], Yolanda De Pro Díaz [1], Domitille Dufour [4], Julián García Mayordomo [5], José Luis Granja Bruña [1], Juan Miguel Insúa Arévalo [1], David Martí [3], Raquel Martín Banda [5], Eulàlia Masana [4], Marc Ollé [4], Elena Pascual Sánchez [1], Juan J. Portela [6], Jhonatan S. Rivera Rivera [6], José Luis Sánchez Roldán [1], Alejandra Staller [6], Sarmad Rameez [4]

[1] Facultad de Ciencias Geológicas, Universidad Complutense de Madrid – Spain
[2] Barcelona-CSI, Institut de Ciències del Mar - CSIC – Spain
[3] Geociencias Barcelona (GEO3BCN), CSIC – Spain
[4] RISKNAT, GEOMODELS, Facultat de Ciències de la Terra, Universitat de Barcelona – Spain
[5] Instituto Geológico y Minero de España, CSIC – Spain
[6] ETSI Topografía, Geodesia y Cartografía, Universidad Politécnica de Madrid – Spain

Seismic hazard depends on the characteristics of the tectonic provinces, the presence of active faults and their complexity and the occurrence of major earthquakes. To produce accurate hazard assessments, it is essential to understand the characteristics of the seismogenic structures, in terms of geometry, interrelation and seismotectonic status. The present-day crustal deformation in southeastern Iberian Peninsula is driven mainly by the NW–SE convergence (4–5 mm/yr) between Africa and Iberia. This convergence is partially accommodated over a wide deformation zone with significant seismic activity. The Plio-Quaternary faulting activity in this area is dominated by a large left-lateral strike-slip system of sigmoid geometry referred to as the Eastern Betic Shear Zone (EBSZ). This active fault system stretches over more than 450 km from Alicante to the south of Almería. The Guadalentin Depression is the main basin within the EBSZ, which corresponds to a NE-SW tectonic corridor bounded by the Carrascoy, Alhama de Murcia and Palomares faults, from north to south. Although a number of active tectonics and paleoseismological studies have been focused in these faults, almost nothing is known about their geometry at depth. To unveil the deep structure, geometry and upper Neogene deformation history of these faults we have carried out a high-resolution multichannel seismic reflection survey. The seismic source consisted of an 8 tonnes vibroseis truck to produce the

*Speaker
†Corresponding author: hperea@icm.csic.es

seismic signal along 2 to 4 km profiles with vibration points spaced 5 m, and recording it with portable seismic stations placed to 10 m interval. The acquired seismic profiles will allow to improve our understanding of the deep geometry of the known active faults (up to 2 km), as well as to identify potential buried branches and will help to reduce the uncertainties in seismic hazard assessment.

Keywords: High resolution multichannel seismic reflection, active faults, fault geometry

Unveiling the Upper Quaternary earthquake history on a large submarine strike-slip fault: The Yusuf Fault System (Alboran Sea)

Hector Perea Manera *† [1,2], Sara Martínez Loriente [1], Jaume Llopart [1], Ariadna Canari [1], Stefanie Almeida [1], Eulàlia Gràcia [1]

[1] Barcelona-CSI, Institut de Ciències del Mar - CSIC – Spain
[2] Facultad de Ciencias Geológicas, Universidad Complutense de Madrid – Spain

The NW-SE convergence (4-5 mm/yr) between Africa and Iberia controls the present-day crustal deformation in the Alboran Sea (westernmost Mediterranean). Although seismic activity is mainly characterized by low to moderate magnitude events, large and destructive earthquakes have occurred in this region. The identification and the seismogenic characterization of the active structures in the Alboran Sea using ultra high-resolution (UHR) geophysical data is essential to characterize better these structures and the exposure of coastal areas to the related natural hazards. The Yusuf Fault System (YFS) is one of the largest active structures in the Alboran Sea. This is a dextral strike-slip fault system that trends WNW-ESE, is _˜150 km-long and has formed of a pull-apart basin. During the SHAKE cruise, we acquired UHR bathymetric (1m grid) and seismic (cm vertical resolution) data across the YFS using autonomous underwater vehicles (AUV). The analysis of the AUV dataset reveals that this system is a complex structure composed by an array of faults, most of them reaching up and offsetting the seafloor and the upper Pleistocene to Holocene sedimentary units. The results of the on-fault paleoseismological analyses reveal that the YFS may have generated at least 8 earthquakes in recent times. The estimated average vertical offset is about 0.64 m while the vertical slip-rate would be around 0.03 mm/yr. However, this value needs to be considered as a minimum since YFS is predominantly a strike-slip fault and the lateral slip will be much larger than the vertical one. According to different empirical relationships, the YFS could produce earthquakes above magnitude Mw 7.0. These results demonstrate that detailed geomorphological, active tectonic and paleoseismological studies are essential to reveal the present-day activity and to characterize the seismic behavior of offshore active faults, with crucial implications for seismic (and tsunami) hazard assessment in the surrounding coastal areas.

Keywords: Submarine paleoseismology, Ultra high resolution offshore geophysical data, Active faults, Alboran Sea

*Speaker
†Corresponding author: hperea@icm.csic.es

The IPOC Creepemter Array in Northern Chile: Potential for a future natural fault observatory

Pia Victor * [1], Anja Schleicher [1], Monika Sobiesiak [2], Salazar Pablo [3], Andreas Güntner [1], Gonzalez Gabriel [4]

[1] GFZ-Potsdam – Germany
[2] CAU Kiel – Germany
[3] UCN Antofagasta – Chile
[4] UCN Antofagasta – Chile

The partitioning of seismic and aseismic behavior in active faults is key for seismic hazard assessment. Surface rupturing fault scarps preserved in the geomorphological record are often interpreted to be the sign of seismogenic faulting and a distinction is made between locked and creeping fault segments. In recent years it became evident though, that faults can transiently change their slip behavior.
The IPOC Creepmeter array in N-Chile (https://www.ipoc-network.org/observatory/creepmeter/creepmeter-at-ipoc/) is a unique fault monitoring network to record transient fault behavior with high resolution. We observe an unprecedented spectrum of slip behavior in the > 10-year long time-series recorded: we have detected accumulation of numerous triggered shallow slip events (SSE), as well as transient creep events. Most of the SSEs are dynamically triggered with durations of 10-2 -180sec. Creep events have event durations up to 12 hours, or they can be climatically triggered by unique rainfall with durations of up to 1,5 years. We now specify the type of slip events in terms of their seismogenic nature according to slip velocities, demonstrating that a spectrum of 10-9m/sec up to 10-3m/sec is covered. Time series decomposition additionally allows us to extract a trend component for 2 of the monitored segments, indicating a slow creep component (< 1mm/year). Furthermore, we correlate specific fault structural and mineralogical properties of rock samples from the sites, with instrumentally monitored slip modes, demonstrating that slip behavior through time can be successfully resolved with this coupled creepmeter/seismometer and structural/mineralogical approach. With this starting point, we will now transform IPOC Creep into a natural fault observatory for the on-site exploration of fault properties in relation to their instrumental behavior, towards a better understanding of the physics of faulting.

Keywords: fault monitoring, seismic/aseismic fault behavior, slip velocity, fault zone properties

*Speaker

Benefits and techniques for using digital photography and structure from motion software in paleoseismic field studies with an emphasis on low-cost methods.

Jason Buck * [1]

[1] TrenchScan – United States

Paleoseismic field studies at locations where surface rupture is evaluated are primary sources from which we learn about earthquake history and surface rupture potential. In cases where field studies are in remote areas or have limited budgets and schedules, the quality and value of the data collected is critically important when planning a field exploration program. Increasingly, investigators around the world have been incorporating the collection of digital photography and image analysis using structure from motion (SfM) software into their workflow to develop high-resolution three-dimensional models of site features. These products are high-quality, objective records of site conditions that can be shared and analyzed long after the field study is completed. This short paper reviews some of the primary benefits, methods, and challenges of two types of data collection: 1) close-range photography of trench exposures, and 2) aerial photography of geomorphic features using small unoccupied aerial vehicles (UAVs). In the interest of promoting the application of these practices and encouraging investigators to incorporate them into their field programs, an emphasis of our analysis is to describe low-cost techniques and minimum efforts to gain benefit. Case studies from a wide range of investigation types will be presented, including small-scale hazard evaluations for private developments to larger, more regional research-grade studies.

Keywords: Structure from Motion, Trench Studies, Unoccupied Aerial Vehicle, UAV, Photogrammetry, Field

*Speaker

Can high-resolution seismic profiles be interpreted similarly to paleoseismological trenches in order to reconstruct the past rupture history of submarine faults?

Sylvain Palagonia * [1], Frédérique Leclerc [1], Hélène Carton [2], Marie Etchebes [3], Cagil Karakas [3], Nugroho Hananto [4], Paul Tapponnier [5], Satish Singh [2]

[1] Géoazur – Université Côte d'Azur, Institut de Recherche pour le Développement : UR082, Centre National de la Recherche Scientifique : UMR7329, Observatoire de la Cote d'Azur – France
[2] Institut de Physique du Globe de Paris – IPG PARIS, Centre National de la Recherche Scientifique : UMR7154, Université Paris Cité : UMR7154 – France
[3] Schlumberger – Schlumberger – France
[4] Research Center for Oceanography, Indonesian Institute of Sciences, Jakarta – Indonesia
[5] National Institute of Natural Hazards, Ministry of Emergency Management of the People's Republic of China – China

The reconstruction of the rupture history of fault systems is key for seismic hazard assessment and understanding short and long-term faulting processes. The rupture history of submarine faults can be established by studying coseismic deposits in sediment cores (Goldfinger et al., 2013) or submarine scarp morphologies with direct on-fault optical observation (Escartín et al., 2016). Another way consists in analyzing faults and related coseismic deposits geometries on seismic reflection profiles. When faults have a significant vertical component of slip, the analysis of vertical offsets and growth sequences can provide evidence of paleo-earthquakes (Pondard et Barnes, 2010). However, when the vertical component of slip is weak, this method is not applicable. Here, we propose a new way to interpret high-resolution seismic profiles by augmenting the mapping of the fault structure with the identification of the sealing sedimentary sequences. Sealing reflectors are used as a proxy for paleoseismological horizons, similarly to horizons interpreted in paleoseismological trenches. They mark the end of a deformation episode that can be associated with (a sequence of) paleo-earthquakes. We applied this method to the strike-slip faults located in the Wharton basin (Indian Ocean). These faults are responsible for the great 2012 Mw8.6 and Mw8.2 earthquakes, the most energetic intra-oceanic events ever recorded thus far (Wei et al., 2013), and their characteristics may indicate a nascent plate boundary (Coudurier-Curveur et al., 2020). We use high-resolution seismic reflection profiles (_˜5 m vertical resolution) acquired in the epicentral area of the Mw8.2 event. As the area shows no seafloor topography and a relatively high detrital sedimentation accumulation rate, conditions are ideal to interpret the seismic data as we propose. Combined with recent IODP drilling in the 2km thick sedimentary basin (McNeill et al., 2017), we can reconstruct the occurrence of deformation (i.e., seismic sequences) over the past 9 Ma.

*Speaker

Keywords: Paleoseismology, Seismic cycle, Submarine faults, seismic reflection profiles

Predicting spatial patterns of landslides induced by the 2010 and 2021 Haiti earthquakes with machine learning methods

Anika Braun * [1], Romy Schlögel [2], Tomas Manuel Fernandez-Steeger [1], Hans-Balder Havenith [2]

[1] (1) Technische Universität Berlin, Department of Engineering Geology – Germany
[2] (2) University of Liege, Department of Geology, Georisk and Environment – Belgium

The 2010 Mw = 7.0 and the 2021 Mw = 7.2 earthquakes, both with epicenters located near the surface expression of the Enriquillo-Plantain-Garden Fault (EPGF), a left-lateral strike-slip fault crossing the southern Haitian peninsula from East to West, have induced significant landsliding, causing numerous fatalities and severe damage to infrastructure.
We used coseismic landslide inventories for the 2010 event (Harp et al. 2016) and the 2021 event (Havenith et al. 2022, under review), respectively, to train Artificial Neural Networks (ANN) to predict spatial patterns of event-related landslide probability based on a dataset consisting of geomorphological and earthquake-related spatial parameters. In order to evaluate the ability of the models to generalize, we applied them to the respective other event area and evaluated their prediction performance with the respective other landslide inventory. During this process, the models were optimized regarding the combination of predictors in the input dataset, with the goal of achieving a model with a good ability to precisely predict landslide susceptible areas, a high ability to generalize, and a simple input dataset, so the models could easily be transferred to other areas.

Based on the results, we could be able to estimate landslide susceptibility for potential future events, for instance along the 60 km long gap between the two fault segments that ruptured in 2010 and 2021, respectively.

References

Harp, E.L., Jibson, R.W., Schmitt, R.G. (2016). Map of landslides triggered by the January 12, 2010, Haiti earthquake: U.S. Geological Survey Scientific Investigations Map 3353, 15 p., 1 sheet, scale 1:150,000, http://dx.doi.org/10.3133/sim3353.
Havenith, H-B, Guerrier, K, Schlögel, R, Mreyen, A-S, Ulysses, S., Braun, A, Victr, K-H, Saint-Fleur, N, Cauchie, L, Boisson, D, Prépetit, C (2022): Earthquake-induced landslides in Haiti: seismotectonic and climatic influences, size-frequency relationships, preprint in NHESS: https://nhess.copernicus.org/preprints/nhess-2022-83/ (currently under review)

*Speaker

Keywords: landslides, earthquake environmental effects, landslide susceptibility, machine learning

Unravelling the recent rupture history of a submarine active fault using video-derived photogrammetry acquired with underwater vehicles

Frédérique Leclerc *† [1], Jérémy Billant [1], Javier Escartin [2], Alex Hugues [3], Klemen Istenic [4], Aurélien Arnaubec [5], Nathalie Feuillet [3]

[1] Géoazur – Université Côte d'Azur, Institut de Recherche pour le Développement : UR082, Centre National de la Recherche Scientifique : UMR7329, Observatoire de la Cote d'Azur – France
[2] Laboratoire de Géologie, ENS Paris – Centre National de la Recherche Scientifique - CNRS – France
[3] Institut de Physique du Globe de Paris – IPG PARIS, Centre National de la Recherche Scientifique : UMR7154, Université Paris Cité : UMR7154 – France
[4] Underwater Robotics Research Center (CIRS), Computer Vision and Robotics Institute (VICOROB), University of Girona, Edifici P-IV, Campus de Montilivi, 17071 Girona – Spain
[5] Institut Français de Recherche pour l'Exploitation de la MER – Institut Français de Recherche pour l'Exploitation de la MER - IFREMER, Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER) – France

Traditionally, the rupture history of an active submarine fault is retrieved by identifying coseismic deposits triggered by earthquakes from sediment cores and/or seismic reflection profiles. The former approach can provide dating of the earthquake but is usually insufficient to evaluate which part of the fault system ruptured and how much was the coseismic slip. Seismic profiles can constrain coseismic deformation but are usually acquired along sparse transects so that the slip reconstruction of past events along strike is incomplete. Here, we show that optical imagery of submarine fault scarps can bring new constraints to complement these methods. Using videos acquired with the remotely operated vehicle Victor (ROV Victor, IFREMER), we investigated the 40 km long Roseau fault, an active normal fault in the Lesser Antilles that produced a Mw 6.3 earthquake in 2004 and triggered a tsunami. With these videos, we derived > 40 georeferenced photogrammetric models of the exhumed scarp at very high-resolution (_˜1 cm), and extending laterally up to 200 m along scarp sections. These methods allow us to cope with light attenuation in water, which reduces the field of sight in the videos to a few meters, and precludes the landscape view of broad areas to evaluate scarp morphology. With the 3D models we were able to identify, map, and measure the last earthquake coseismic deformation along the 40 km long fault. We also identified paleo-seafloor markers located directly on the exposed fault plane that we interpret to be linked to the exhumation and rupture history of the fault. We are now able to evaluate seismic history of submarine fault at appropriate scales and with techniques approaching onland type of studies.

*Speaker
†Corresponding author:

Keywords: Paleoseismology, submarine faults

Remote sensing of active tectonics in the Eastern and Southern Alps

Christoph Gruetzner * [1], Manuel Diercks [2], Mattis Grenier [3], Klaus Reicherter [4], Kamil Ustaszewski [1]

[1] University of Jena – Germany
[2] University of Plymouth – United Kingdom
[3] University of Cambridge – United Kingdom
[4] RWTH Aachen University – Germany

The Eastern and Southern Alps are deforming due to the collision of the European and Adriatic plates. About 3 mm/yr of northward motion of Adria are taken up mainly by thrusting along the South Alpine Front and by strike-slip faulting in W Slovenia. Historical and instrumental seismicity as well as geodetic data show that some deformation is also accommodated further north, but little is known about which faults are active in the interior of the Alps. Here we present results from a remote sensing study that aimed at identifying areas with tectonic activity based on landscape features. We used high-resolution digital elevation models from aerial laser scanning campaigns downsampled to 5 m resolution to balance resolution and computing time/file handling. From these DEMs we calculated the most used geomorphic indices that might indicate active tectonics: the surface roughness, the terrain ruggedness index, and the surface index, which is a combination of surface roughness and hypsometric integral. Drainage system analysis was done using the normalised steepness index, stream knickpoints, hypsometric curves, hypsometric integrals, the basin asymmetry factor, and the χ value. We compare our results with published geological maps, fault databases, and seismicity data. Field work was done to verify the results. Our study shows that several factors complicate the application of large-scale tectonic geomorphology in the Alps to an extent that makes it almost impossible to achieve meaningful results. It is difficult to account for changing lithologies over short distances. Strong variations in bedding and occasionally vertical strata lead to false positive signals. Karst features dominate the drainage in large areas and prohibit the use of standard techniques that are based on landscape sculpturing by rivers. Glacial features have overprinted the traces of known faults. We discuss ways to overcome some of these problems and we highlight potential pitfalls.

Keywords: remote sensing, Alps, tectonic geomorphology

*Speaker

Styles of Quaternary deformation along the south-central Chilean forearc revealed by LiDAR

Daniel Melnick * [1], Luis Astudillo [2], Joaquin Cortes-Aranda [2], Valeria Flores [1], Julius Jara-Muñoz [3], Roland Freisleben [3], Roberto Larregla [1], Valentina Maldonado [1], Mauricio Espinoza [4]

[1] Universidad Austral de Chile – Chile
[2] Universidad de Concepción – Chile
[3] University of Potsdam – Germany
[4] Universidad Catolica de la Santisima Concepcion – Chile

Although only a handful of instrumentally-recorded crustal earthquakes have occurred in Chile, several potentially-active faults have been mapped and classified in the CHilean Database of Active Faults (CHAF) at 1:25,000 scale. The database includes 958 fault strands grouped in 17 systems based on geometric and kinematic characteristics and is available at www.fallasactivas.cl and PANGAEA. Empirical relations suggest some of these faults may be capable of generating M> 7 earthquakes, in agreement with paleoseismic studies. However, other fault systems appear to be rather associated with aseismic slip and may not pose such a high seismic hazard. Here, we use bare-earth digital terrain models (DTM) from airborne LiDAR acquired by forestry companies at regional scale to show different styles of active deformation along the south-central Chilean forearc. Along the coast, we identified several faults that offset MIS-5e marine terraces and extend into the Coastal Cordillera. Along the Central Depression, an onshore Cenozoic forearc basin, we identified 4 areas of 400-1200 km2 characterized by distributed deformation across _˜30-km-wide belts that include tens of discrete faults, cracks, and furrows. Some regions include polygonal faulting. Distributed faulting is associated with Quaternary sediments, which have greater thicknesses than in the surroundings. We interpret distributed polygonal faulting along the Western Andean Mountain front as lateral collapse of two piedmont fans of Plio-Pleistocene age, which are uplifted and disconnected from the modern drainage system, in response to slip along a buried thrust system. Farther south, other regions of distributed faulting are associated with Pleistocene glacial sedimentary cover, and intersections of regional faults such as the Mocha-Villarica system. Faults in these distributed-deformation regions have lengths of < 8 km, may be associated with aseismic slip.

Keywords: LiDAR, distributed deformation, forearc, Chile

*Speaker

3D geological model of the northeastern part of the Cevennes Fault System (CFS) (France)

Camille Thomasset * [1,2], Sylvain Pouliquen [2], Jean-François Ritz [1], Nicolas Cathelin [1,3], Romain Le Roux-Mallouf [2], Kévin Manchuel [2], Stéphane Baize [3], Matthieu Ferry [1]

[1] Géosciences Montpellier – Institut National des Sciences de l'Univers : UMR5243, Université de Montpellier, Centre National de la Recherche Scientifique : UMR5243, Université des Antilles – France
[2] EDF – EDF – DIPNN, Aix-en-Provence, France – France
[3] Institut de Radioprotection et de Sûreté Nucléaire – Institut de Radioprotection et de Sûreté Nucléaire – France

The Mw4.9 Teil earthquake occurred on November 11, 2019 along the La Rouvière fault, a fault belonging to the Cévennes fault system (CFS), which was not mapped as potential active fault. Following this unprecedented shallow earthquake, several studies were launched to understand the geology, the seismology, as well as the rheology of the fault and its structural environment in the first 2 km below the surface. Despite these works, the general structure of CFS remains poorly known and the geology of the Montélimar basin is only constrained by three deep boreholes that show significant lateral variations in the sedimentary units thicknesses.
In this paper we present the results of the acquisition of 70 km of high-resolution (HR) seismic lines, bringing new data to image the CFS down to about 8 km depth. These data, coupled with field observations, allow building up a 3D structural model of the area. We show that the major faults correspond to listric normal faults resulting from a polyphased tectonic history, rooted on a Triassic detachment level. Some fault segments observed on the profiles are not visible at surface, remaining hidden under the thick alluvial deposits of the Rhone River Valley. The relationships between these faults, affecting the sedimentary cover and the basement remains to be refined using gravitational data. In the near surface, UHRS profiles (ultra-high resolution seismic) performed where recent deposits are located directly above the faults imaged in the subsurface will allow to define sites where paleoseismological trenches could be opened.
This works, with that of Nicolas Cathelin, are carried out in the framework of the CNRS-INSU-FREIMTEIL project with the support of EDF and IRSN, respectively. Together, they will provide up to date data on CFS that will be helpful for seismic hazard assessment in this part of the Rhone River valley.

Keywords: Basin analysis, seismic lines, structural, active faults, paleoseismology

*Speaker

Segmentation of the Trévaresse thrust system (Provence) from airborne LiDAR topography and field mapping. Implications for paleosismic investigations on the Lambesc 1909 earthquake.

Magali Rizza * [1], Laurent Bollinger [2], Pablo Manzanares [1], Yann Klinger [3], Jules Fleury [1], Bellier Olivier [4], Lionel Siame [1], Véronique Rinalducci [1]

[1] Centre européen de recherche et dénseignement des géosciences de lénvironnement – Institut de Recherche pour le Développement : UMR$_D$161, $AixMarseilleUniversité : UM34, CollègedeFrance : UMR7330, InstitutNationaldesSciencesdel'Univers, CentreNationaldelaRechercheScientifique : UMR7330, InstitutNationaldeRecherchepourl'Agriculture, l'Alimentationetl'Environnement : UMR1410 --France$

[2] Commissariat à l'énergie atomique et aux énergies alternatives (CEA) – MESR, Ministère de la défense – BP12. 91680 BRUYERES LE CHATEL, France

[3] Institut de Physique du Globe de Paris (IPGP) – INSU, IPG PARIS, Université Paris Diderot - Paris 7, Université de la Réunion, Centre National de la Recherche Scientifique : UMR7154 – IPGP, 1 rue Jussieu, 75238 Paris cedex 05 ; Université Paris Diderot, Bât. Lamarck A case postale 7011, 75205 Paris CEDEX 13, France

[4] Centre européen de recherche et d'enseignement de géosciences de l'environnement (CEREGE) – Aix Marseille Université, INSU, Institut de recherche pour le développement [IRD], CNRS : UMR34 – Europôle Méditerranéen de l'Arbois - Avenue Louis Philibert - BP 80 - 13545 Aix-en-Provence cedex 4, France

On June 11th 1909, an earthquake affected France southeastern quarter. The location of the mesoseismal zone, the location of the macroseismic epicenter, as well as the focal mechanism retrieved from the instrumental records, suggest that the event occurred on the Trévaresse fold and thrust system. The moment magnitude associated falls between Mw=5.5 and 6.0, making it the strongest instrumental earthquake in mainland France.
Studies carried out in the early 2000s attest that the Trévaresse fault was most probably responsible for the 1909 Lambesc earthquake. However, the morphotectonic and paleoseismological studies carried out in the region do not allow us to properly constrain the ages of the paleoruptures and the return times associated with this fault system.

Several questions are still debated, requiring further studies. The lateral variability of the surface expression of the rupture remains poorly documented. Indeed, the geomorphological expression of the front of the Trévaresse range is subtle and the choice was made by the previous teams to document it in detail on the eastern half of the Trévaresse fold system.
Since the previous published studies, an airborne Lidar Survey with a submetric resolution has been acquired over the area. Geomorphological mapping reveals subtle reliefs at the front of

*Speaker

the thrust system, including many fault strands. 19 fault segments were identified. Despite lateral variations in the orientation of the fault segments and their surface expression, the western part of the fault system presents analogies with the eastern part. The toe of the Trévaresse fold presents several distinct fault strands, relatively well expressed. But the deformation also spread several hundred meters further south in the colluvium of slopes and alluvial deposits.This new fault mapping suggests that the length of the rupture surface could even exceed 13.5 km.

Keywords: Lidar survey, paleoseismology, surface rupture

Characterization of normal fault scarp using convolutional neural network: application to Mexico

Lea Pousse-Beltran * [1], Sophie Giffard Roisin [2], Laurence Audin [1], Pierre Lacan [3], Theo Lallemand [1], Andres Núñez Meneses [3], Glenn Cougoulat [4]

[1] Cycle sismique et déformations transitoires – Institut des Sciences de la Terre – France
[2] Isterre – Institut des Sciences de la Terre – France
[3] Universidad Nacional Autónoma de México – Mexico
[4] Laboratoire Jean Kuntzmann – Institut National de Recherche en Informatique et en Automatique, Centre National de la Recherche Scientifique : UMR5224, Université Grenoble Alpes, Institut polytechnique de Grenoble - Grenoble Institute of Technology – France

Fault markers in the landscape (scarps, offset rivers) are records of fault activity. The geomorphological characterization of these markers is currently a time-consuming step with expert-dependent results, often qualitative and with uncertainties that are difficult to estimate. To overcome those issues, we are developing supervised machine learning methods using convolutional neural networks (CNN) trained on a database of simulated topographic profiles across fault scarps.
We have developed a one-dimensional CNN for the characterization of active faults in the Trans-Mexican Volcanic Belt. This region is affected by more than 600 potentially active faults but less than 5% of those have been correctly characterized by paleoseismological studies. In this context a robust and automatic method to characterize the escarpments in a global, reproductible, robust (not expert-dependent) quantitative way will be invaluable and a great step towards a better characterization of the seismic hazard of the region.
From this specific case study, we will explore the advantages (computation time, accuracy, uncertainties) and limitations (such as bias) that machine learning methods bring to the field of morphotectonics.

Keywords: Morphotectonics, machine learning

*Speaker

Effects of sampling biases in extracting throw measurements along complex fault geometries from seismic reflection datasets

Billy Andrews * [1], Zoë Mildon [1], Christopher Jackson [2]

[1] University of Plymouth – United Kingdom
[2] University of Manchester – United Kingdom

Quantifying the geometry and slip-rate along non-planar normal faults represents a key challenge in assessing the seismic hazard posed by intercontinental earthquakes. Field data from the Central Apennines, Italy, has shown slip-rate can vary through time and may be elevated within fault bends. To understand how slip-rate evolves through geological time seismic reflection datasets of inactive or active fault systems may be utilised. To accurately capture fault properties, measurements should be taken orthogonal to fault strike, which is easy to do for 3D seismic surveys using arbitrary lines (arblines), but where only 2D surveys exist (either onshore or offshore, these may not be optimally orientated to active fault structures. The question becomes when seismic survey lines are mis-orientated compared to the normal fault structures of interest, what is the implication for the accuracy of the extracted fault properties such as throw? This is also important when studying fault bends in 3D seismic surveys where rapid changes in fault strike may require multiple arblines to correctly capture fault geometry. In this study we use high resolution 3D seismic data from offshore Australia to systematically investigate how mis-orientated interpretations affect discontinuous and continuous throw recorded on relatively straight normal faults. We pick fault offsets every 100 m using arblines constructed every 10∘ from orthogonal to fault strike to +/- 50∘, simulating the possible rage of mis-orientation that may be encountered. Using throw backstripping we investigate how throw and slip-rate evolved through several million years. Our data shows that where data is collected at 20∘ to the fault strike, the median error in slip-rate measurement can exceed 25%, increasing as the angle of mis-orientation increases. Finally, we highlight the magnitude of error caused by not sampling orthogonal to the local fault strike and discuss the importance for seismic hazard assessment.

Keywords: Slip rate, Myr slip rates, Seismic reflection data

*Speaker

Factors Affecting Deposition of Turbidite-Homogenite Units in Kumburgaz Basin, Sea of Marmara

Nurettin Yakupoğlu [1], Pierre Henry *† [2], Gülsen Uçarkuş [3], K. Kadir Eriş [4], François Demory [5], Christian Crouzet [6], M. Namık Çağatay [7]

[1] Istanbul Technical University, Geological Engineering Department, EMCOL Applied Research Center, Faculty of Mines, Ayazağa, 34469 İstanbul, Turkey – Turkey

[2] Centre Européen de Recherche et d'Enseignement des Géosciences de l'Environnement – Aix Marseille Université : UM34, Centre National de la Recherche Scientifique : UMR7330, Institut de recherche pour le développement [IRD] : UMR161, INRAE, Collège de France, Paris Sciences et Lettres University, Paris – France

[3] Istanbul Technical University, Geological Engineering Department, EMCOL Applied Research Center, Faculty of Mines, Ayazağa, 34469 İstanbul, Turkey – Turkey

[4] Istanbul Technical University, Geological Engineering Department, EMCOL Applied Research Center, Faculty of Mines, Ayazağa, 34469 İstanbul, Turkey – Turkey

[5] Centre Européen de Recherche et d'Enseignement des Géosciences de l'Environnement – Aix Marseille Université, CNRS : UMR7330, Institut de recherche pour le développement [IRD] : UMR161, Institut national de la recherche agronomique (INRA) : US1410, Collège de France – France

[6] Institut des sciences de la Terre (ISTerre) – Université de Savoie Mont Blanc, CNRS : UMR5275 – Technolac 73376 Le Bourget du Lac cedex, France

[7] Istanbul Technical University, Geological Engineering Department, EMCOL Applied Research Center, Faculty of Mines, Ayazağa, 34469 İstanbul, Turkey – Turkey

In the Sea of Marmara deep basins, Turbidite-Homogenite (TH) event occurence has been related to the recurrence of large earthquakes (M> 6.8) on adjacent segments of the North Anatolian Fault that has been estimated to 200-250 years from historical records (McHugh et al., 2014; Parsons et al., 2004; Ambraseys, 2002). THs are typically 3-to-50 cm thick, with a basal turbidite layer comprising alternating laminae of sand and mud, overlain by a layer of clay and fine silt (the homogenite) with little variation in grain size distribution and composition. In a 21-m-long calypso core (MRS CS-14) recovered from Kumburgaz Basin (_˜-833 m depth) comprising a succession of facies (lacustrine and marine with a laminated sapropel interval) over the last ≈15000 years, 70 THs were identified based on visual observations, gamma densimetry, elemental chemistry from μ-XRF scanning, and anisotropy of magnetic susceptibility. Magnetic foliation is generally higher in homogenites than in background sediment, allowing accurate determination of events thicknesses. After removal of TH intervals, an age model for the background sediment constrained with calibrated 14C ages is calculated with CLAM script. Background sedimentation rates are assumed to vary smoothly and found to range from 0.6 mm/yr to 1.2 mm/yr. Applying this model, the average time interval elapsed between TH events is found to be highly variable, being about 200 years during the lacustrine period, exceeding 500 years during the deposition of the laminated sapropel, and displaying important variations from 60 years to 200 years within

*Speaker

†Corresponding author: henry@cerege.fr

the later marine sediment interval. It thus appears that the interval between TH events only matches the reported recurrence of historical earthquakes during specific time intervals. Besides variations of earthquake recurrence, variations of sea or lake level, of sediment flux and of sediment geomechanical properties are among the possible factors influencing slope instability and TH event occurence.

Keywords: Marine paleoseismology, Turbidite, homogenites, Sea of Marmara, North Anatolian Fault

3D paleoseismic trenching combined with 3D geophysics

Petra Štěpančíková * [1], Tomáš Fischer [2], Thomas Rockwell [1,3], Petr Tábořík [4], Jakub Stemberk [1], Magda Karousová [5], Jakub Široký [2], Marlena Yaneva [6], Alexander Radulov [6], Yordanka Donkova [6], Hamid Sana [1], Filip Hartvich [1]

[1] Institute of Rock Structure and Mechanics, Czech Academy of Sciences – Czech Republic
[2] Faculty of Science, Charles University in Prague – Czech Republic
[3] San Diego State University – United States
[4] Institute of Rock Structure and Mechanics, Czech Academy of Sciences – Czech Republic
[5] Faculty of Science, Charles University in Prague – Czech Republic
[6] Geological Institute, Bulgarian Academy of Sciences – Bulgaria

We carried out paleoseismic study at the Kopanina site studying NNW-SSE trending Mariánské Lázně Fault (MLF), which is situated in the western part of the Bohemian Massif (Czech Republic, Central Europe). The MLF is morphologically pronounced and controls the eastern limit of the Cheb-Domažlice Graben for a length of 100 km, and Cheb basin in its northern portion, which intersects with NE-trending Cenozoic Eger rift. The Cheb basin is famous for Mid-Pleistocene volcanism, abundant occurrences of mantle-derived carbon-dioxide emanations, and present-day earthquake swarms (Mw $\leq$ 4.0), which are aligned along NNW-trending fault. This seismogenic fault intersects the NW-trending MLF around Kopanina area, which shows no clear present-day seismicity but which generated prehistorical surface-rupturing earthquakes resulting in present-day morphology as revealed by our paleoseismic trenching. Due to prevailing strike-slip kinematics of the younger events, we applied 3D trenching to explore horizontal displacements and the fault zone structure. We excavated seven backhoe trenches and six hand-dug micro-trenches, which revealed a complex structural set-up with oblique faults and deformation probably as a result of right-lateral transpression during the Late Quaternary. Trenching was preceded as well as accompanied by geophysical survey. The geophysical survey aimed to reveal shallow subsurface 3D structure of the MLF at Kopanina site by extending the inferred geological information spatially and to the depth. The survey presented here comprised 3D GPR (with 25 cm interval lines), DEMP (dipole electromagnetic) mapping, and 2D and pseudo-3D electric resistivity profiles. The results revealed horizontally offset sedimentary bodies, which are well reflected in 3D geophysics at a greater (meters) scale and with best resolution obtained by 3D GPR. On the other hand, trenching and even micro-trenches enabled to reveal smaller (centimeters) offsets. Thus, combining 3D trenching and 3D geophysics appeared to be a very useful way to display fault characteristics, especially in strike-slip regime.

Keywords: paleoseismic 3D trenching, geophyiscal survey, 3D geophysics, fault structure, Mariánské

*Speaker

lázně fault, Cheb Basin, Bohemian Massif

Characterization of the San Ramón Fault active scarps from LiDAR data: A case study from the West-Andean thrust front.

Angelo Villalobos *† [1,2], Gabriel Easton [1], Nicolás Campillay [1]

[1] Geology Department, University of Chile – Chile
[2] Civil Engineering and Geology Department, Catholic University of Temuco – Chile

High-accuracy and high-resolution topography are essential for the study of active faults. A high-resolution LiDAR DEM (1 cubic meter pixel) of the western Andean piedmont at the vicinity of Santiago (Chilean capital city) was made from data taken using Optech ALTM 3100 EA Airborne Laser Terrain Mapper System. In 2015 a first campaign covered most of the urban area of interest, and in 2019 was expanded to the southern communes (Puente Alto, Pirque, and La Florida). Our objective was to detect and characterize the structure geometry and geomorphological features of the San Ramón Fault (SRF), a _˜50 km long west-verging reverse active fault affecting highly urbanized areas. We studied the entire known fault by systematic analysis using 1,000 topographic profiles spaced every _˜50 m, and orthogonal to the fault strike. The identified lineaments present fault scarps (surface ruptured earthquakes) with vertical offsets of geomorphologic surfaces, and terrain bulges (subsurface ruptures earthquakes). Based on the four different types of scarps founded, it was possible to map by segments of the SRF trace. Also, using this method we quantified morphometric parameters (e.g. scarp elevation, slope, aspect, vertical separation). The combined analysis of the DEM-derived parameters allows us to (a) define features of three-dimensional scarp geometry, (b) decipher its geomorphological significance linking landforms and structure in depth, and (c) (re)defining geometry of known and new segments of the SRF trace.

Keywords: airborne LiDAR, active fault, quantitative tectonic geomorphology, coseismic offset, cumulative offset

*Speaker
†Corresponding author: angelovillalobos42@ug.uchile.cl

Seismotectonic activity in the NW Cotentin Peninsula (Normandy, France). The input of offshore high-resolution data.

Tassadit Kaci *† [1], Anne Duperret [1], Yann Méar [2], David Graindorge [3], Bernard Le Gall [3], Julie Perrot [3], Stéphane Baize [4]

[1] UMR CNRS 6294 LOMC – Université Le Havre Normandie, France. – France
[2] EA 4253 LUSAC – CNAM-INTECHMER, Cherbourg-en-Cotentin, France – France
[3] IUEM, UMR CNRS 6538, Géosciences Océan – Université de Bretagne Occidentale (UBO), Plouzané, France – France
[4] Institut de Radioprotection et de Sûreté Nucléaire – BERSSIN, BP17, Fontenay-aux-Roses, 92262, France – France

The North Cotentin Domain, covering the Cotentin peninsula and the Normano-Breton Gulf, is characterized by a low to moderate intraplate seismicity. The study domain is a unique region in Europe, where three orogens have succeeded between 2000 and 300 Ma. The question is to understand whether the polyphased structural network controls the location of the current deformation. The proposed analysis is a combination of offshore geomorphology, seismicity relocation and focal mechanisms analyses.

A new high-resolution bathymetry map was compiled from the combination of multibeam echosounder acquired during SHOM campaigns and shallow water R/V Haliotis cruises. A high-resolution land-sea DEM is produced using RGE-Alti and LIDAR data (IGN/SHOM) completed with geological units map (BRGM), onshore field structural observations and measurements. Offshore data have revealed a complex geological scheme and fracture set within the Palaeozoic to Mesozoic bedrock, mainly dominated by strike-slip faults, with 1) dextral N150◦E-170◦E, 2) N40◦-70◦E and 3) sinistral N140◦E-160◦E trending. We assume these fault systems are related to Variscan orogeny. However, their potential reactivation in the neotectonic period (Quaternary) and their relationship to La Hague fault (Jomard et al., 2017) is still an open question.

For current earthquake analysis, we focused on the P-wave first motion polarities of recent earthquakes recorded by the RESIF and BGS seismic networks, located near Jersey (2014 and 2015) and Coutances (2020). We used only the closest stations and a regional velocity model (Amorèse, 2000), producing different epicentral relocation than the ReNaSS one. For instance, the previously inferred alignment near Jersey (2014-2015 sequence) changed and the earthquake depth increased from 7 to 12km. Focal mechanism solutions show also strike-slip components from N150◦-170◦E and N70◦-90◦E. When plotting this seismicity on existing geological section, we conclude that those earthquakes could be linked to the reactivation of major Variscan structures, but also Cadomian N70◦E shear zone.

*Speaker
†Corresponding author: tassadit.kaci@univ-lehavre.fr

Keywords: Cotentin, Structural inheritance, Submarine geomorphology, Seismicity, Active fault

An innovative quantitative method for recovering paleoseismic record from subaqueous sedimentary sequence

Yin Lu * [1], Nadav Wetzler [2], Nicolas Waldmann [3], Amotz Agnon [4], Glenn Biasi [5], Shmuel Marco [6]

[1] University of Innsbruck – Austria
[2] Geological Survey of Israel – Israel
[3] University of Haifa – Israel
[4] Hebrew University of Jerusalem – Israel
[5] US Geological Survey – United States
[6] Tel Aviv University – Israel

Trenching-based paleoseismology can extend the record of surface rupturing earthquakes to the past few thousand years. However, these technics not feasible in subaqueous environments since faults are usually inaccessible. Subaqueous paleoseismology exploits earthquake-induced event deposits that are preserved in lacustrine and marine sedimentary sequences, can extend the record of earthquakes, and promote the understanding of long-term fault behavior.
Since faults in subaqueous environments are inaccessible, it's not possible to estimate earthquake intensity or magnitude based on fault rupture features. One way to achieve this is by investigating the physical features of earthquake-deformed structures. The Dead Sea typical *in situ* deformed structures are featured by layer-parallel displacements, similar to Kelvin–Helmholtz turbulence in other environments. Earthquake-forced shear, leading to sediment turbulence called the Kelvin–Helmholtz Instability, is a plausible driver for the deformation. Under seismic shaking, water-saturated stratified layers could move horizontally in the same direction but with different velocities, creating shear that localizes at the layer interfaces.
Based on the Kelvin-Helmholtz Instability, we model the ground acceleration needed to produce each deformation by using the physical properties of the Dead Sea deposits. By considering both the shape and thickness of the deformed structures, we can determine the intensity that each deformed layer is representing. We invert acceleration for earthquake magnitude by considering regional earthquake ground motion attenuation, fault geometry, and other constraints. Based on the magnitude constraints, we develop a 220 kyr-long continuous record of Mw $\geq$7 earthquakes. Our unique record confirms a clustered earthquake recurrence pattern and a group-fault temporal clustering model, and reveals an unexpectedly high seismicity rate on a slow-slipping plate boundary. Our quantitative method of seismic record reconstruction, with paleo-earthquake intensity and magnitude estimation, is also applicable to other subaqueous environments along faults.

*Speaker

Keywords: Computational fluid dynamics modeling, Kelvin Helmholtz Instability, Subaqueous Paleoseismology, Seismite

Measuring spatial anomalies of radon to explore their usability to study active fault zone in Ambarawa, Central Java, Indonesia

Gayatri Indah Marliyani *† [1], Agung Harijoko [1], I Gde Sukadana [2], Pepen Supendi [3], Hurien Helmi [4], Salma Fatria Pertiwi [1]

[1] Geological Engineering Department, Universitas Gadjah Mada – Indonesia
[2] Nuclear Power Research Organization, National Research and Innovation Agency – Indonesia
[3] Agency for Meteorology, Climatology, and Geophysics – Indonesia
[4] Geological Engineering Department, Institut Teknologi Nasional Yogyakarta – Indonesia

The spatial variability of radon, a naturally-occurring radioactive soil gas produced by the uranium (U) and thorium (Th) decay in rocks from the deeper crust, may indicate the occurrence of fractures or faults as a preferred permeable pathway, allowing upward migration of the carrier gases. The short-lived nature of radon (222Rn) and thoron (220Rn) (half lifetime of 3.824 day and 55.6 sec, respectively) signifying their surface accumulation as an indicator for the occurrence of permeable pathway such as fault zone. Here we present the results of the radon measurement survey using Durridge Rad-7 as a quantitative radon thoron detector in Ambarawa, Central Java, Indonesia. We conduct the survey as part of an integrated research to locate active faults responsible to the tens of shallow crustal earthquakes with a magnitude range 2-3.6 occurred within the month of October 2021. The epicenter area is close to the highly populated Ambarawa, Salatiga and Ungaran towns, highlighting the importance of characterizing active faults in this area. We were able to locate faults that are displacing Quaternary sediments through field mapping, but the continuation of the fault trace is unclear. At one among the limited fault outcrops, the fault displaced stratigraphic unit consist of an intercalation of lake and volcanic ash deposits. The fault cropped at several other locations and show a consistent fault strikes to the NE and NW. We established a total of 63 radon measurement points along the estimated fault trace projected from these limited outcrops. Our preliminary data analysis indicates positive anomalous radon values and ratios along the estimated fault trace, and we could use their spatial distribution to confirm the previously unknown fault location. Our study will contribute to the refinement of the seismic hazard analysis of the area and test radon analysis's usability to study active faults.

Keywords: radon, thoron, permeable zone, soil gas, seismic hazards, active faults

*Speaker
†Corresponding author: gayatri.marliyani@ugm.ac.id

Horizontal offset measurements along the surface rupture of the 1995 Kobe earthquake from aerial photo correlation using MicMac

Jin-Hyuck Choi *† [1], Han-Kyung Bae [1], Yann Klinger [2], Dong-Eun Kim [1], Arthur Delome [2]

[1] Korea Institute of Geoscience and Mineral Resources – South Korea
[2] Institut de physique du Globe de Paris – Institut de Physique du Globe de Paris – France

One of the most recent tools to map the surface ruptures during the earthquakes is to correlate optical images of the ground acquired before and after the seismic event. Here we introduce results of image correlation for the surface rupture during the Jan. 17, 1995 Mw 6.9 Kobe earthquake, Japan. A pair of aerial images, which were acquired on Apr. 21, 1991 (pixel size of 0.5 m) and Jan. 20, 1995 (pixel size of 0.2 m) by GSI in Japan, was correlated using MicMac to trace rupture geometry and to measure horizontal offset. Preliminary results show that both rupture geometry and horizontal offset are in general in accordance with post-event field observations. Meanwhile, we could detect distributed deformations and along-fault continuous variations of horizontal offset, which have not been reported by the previous field observations. We mainly discuss the differences between the previous and our mapping results, and their implication in to fault-rupture behaviors.

Keywords: Kobe earthquake, surface rupture, horizontal offset, image correlation, MicMac

*Speaker
†Corresponding author: cjh9521@kigam.re.kr

ADVANTAGES OF RETRODEFORMING TRENCH LOGS

James Mccalpin * [1]

[1] GEO-HAZ Consulting, Inc. – United States

Retrodeformation of a vertical trench wall log involves a stepwise graphical reconstruction of the wall geometry backwards in time from present. Often retrodeformation will reveal that the trench log as mapped cannot be retrodeformed, indicating that one or more trench wall contacts was mis-mapped. If the trench is still open when this is discovered, the offending contact can be re-examined. But if the trench has been backfilled, correcting it to a viable retrodeformation sequence becomes problematic. Thus, retrodeformation should be performed while the trench walls are still accessible. Prior to the mid-1990s most published trench logs had not been "reality-checked" by retrodeformation. So the interpreted sequence of deformation events was intuited by simply looking at the log and observing obvious cross-cutting relationships and angular unconformities. This was acceptable if there were few faults on the wall and few events. But as the number of faults and events on the log increased, this subjective approach was unable to measure displacement on each exposed fault strand during each displacement event. That can only be accomplished with retrodeformation. We offer several case histories of 2D, rigid-block retrodeformation of trench logs on dip-slip faults that exposed multiple displacement events. One case history from 1991 in the western USA illustrates how failing to perform a retrodeformation led to an incorrect estimate of fault recurrence. Thirty years later that same fault became to closest active fault to a proposed nuclear power plant, and the error was uncovered during seismic source characterization for the probabilistic seismic hazard assessment (PSHA).

Keywords: trenching, trench logs, interpretation

*Speaker

Robotic mapping, machine learning, and particle dynamics for earthquake geology

Ramon Arrowsmith Et Al. *† [1]

[1] University of Arizona – United States

Documenting and interpreting the interaction between surface and tectonic processes for records of earthquakes in the landscape is a central challenge for both fundamental understanding and application to hazard assessment. Advances in the automation and scaling of data collection and data analysis for earth sciences are evident from robotics and artificial intelligence (or machine learning–ML). Central to the practice of robotic science is an end-to-end system from simulation to application. Robot Operating System facilitates robot design and development; simulation tools with powerful physics engines (e.g., Gazebo, Bullet) verifies robotic systems for potential field applications; ML enables online geologic feature detection and active sampling. In this talk, I will illustrate the potential for these tools in advancing earthquake geology including searching for, mapping, and analyzing the dynamics of fragile geologic features. Measuring rock fragility can be challenging at scale. Our work on ML-based mapping of rock traits (size, orientation, ellipticity) of _˜240k particles on rocky
fault scarps provides a new view for interpreting process and the effect of changing slip rate. Besides rock detection in 2D orthomaps, we present rock detection and mapping in 3D point clouds. These 3D objects may be precarious and thus negative indicators of strong ground motion.
Interpreting their stability may be done using our "virtual shake robot" (VSR). The VSR allows for exploration of the effects of input ground motion histories on the fragility of arbitrarily complex objects and substrates with realistic physics. These tools present an important new set of capabilities for earthquake geology and beyond.

Keywords: earthquake geology, Machine learning

*Speaker

†Corresponding author: ramon.arrowsmith@asu.edu

Active Subaquatic Fault Segments in Lake Iznik along the Middle Strand of the North Anatolian Fault, and paleoseismicity of the NAF, NW Turkey

J. De Sigoyer Et Al. *† 1

[1] Institut des Sciences de la Terre – Institut National des Sciences de l'Univers, Institut de recherche pour le développement [IRD] : UR219, Université Grenoble Alpes, Université Gustave Eiffel, Centre National de la Recherche Scientifique : UMR5275, Université Savoie Mont Blanc – France

The western termination of the North Anatolian Fault (NAF) shows a complex geometry as it is divided into three branches, the Northern, the Middle and the Southern NAF (NNAF, MNAF, SNAF respectively). The slipping rate of MNAF and the SNAF is 5 time less rapid than the NNAF 25 mm/yr. No earthquake was recorded since 150 yrs on the MNAF, while many earthquakes were documented on it since 2000 yr.
Geophysical and paleolimnological studies (30 cores) on the Iznik Lake, associated to the fault, were achieved to better understand the structure of this fault and retrieved past earthquakes recorded by the lake sediments.
Two active fault segments were identified for the first time into the Iznik lake. One, the Iznik fault, is very linear. It cross cut the Iznik lake and is connected to the on-land segment. The cores sampled from both part of the fault indicate that the Iznik fault has ruptured for the last time in 1065. 15 other earthquakes were identified in the cores since almost 2000 yrs. No earthquake was recorded after the 1065 in the Iznik lake. This event recorded in all the cores of the lake, has totally purged the slopes of the lake Iznik. This earthquake may have triger a tsunami and has implied the destruction of a basilica located on the Iznik shore. It has also changed the sensibility of the lake to earthquakes. The current seismic gap of more than thousand years on this segment greatly increases the seismic hazard in this region and must be considered in the seismic risk assessment of the NAF system.

Keywords: lacustrine paleoseismology, North Anatolian Fault

*Speaker
†Corresponding author: julia.de-sigoyer@univ-grenoble-alpes.fr

Contributions to seismic hazard analysis

Why do seismic hazard maps overpredict historically observed shaking?

Molly Gallahue *† [1], Leah Salditch [2], Madeleine Lucas [3], James Neely [1], Seth Stein [1], Norman Abrahamson [4], Tessa Williams [4], Susan Hough [2]

[1] Northwestern University – United States
[2] US Geological Survey – United States
[3] University of Washington – United States
[4] University of California, Berkeley – United States

Seismologists have recently begun assessing how well probabilistic earthquake hazard models and corresponding maps forecast shaking that actually occurs. Based on several metrics, current hazard maps for California appear to overpredict the level of high-frequency shaking shown by the California Historical Intensity Mapping Project (CHIMP) dataset of maximum observed shaking from the largest Californian earthquakes between 1857 and 2019. Understanding this overprediction, which is qualitatively similar to that observed in France, Italy, Japan, and Nepal, could lead to improved seismic hazard maps for California and, by extension, worldwide. There are three possible reasons for the discrepancy between observed and predicted shaking: hazard maps may be biased high, historical data may be biased low, or misfit may arise by chance. A prior evaluation used several simplifying assumptions. We examine three assumptions to determine if they cause the overprediction: 1) not considering site effects from variations in VS30 (time-averaged shear-wave velocity in the top 30m of soil), which could amplify or deamplify ground motions relative to the reference hazard map, 2) assuming the CHIMP data set is complete at magnitude 5 used as the minimum magnitude (**MMin**) in hazard calculations, and 3) not considering aleatory variability in the conversion from peak ground acceleration (PGA) to Modified Mercalli Intensity (MMI) ground motions. We show that incorporation of site-specific VS30 does not appreciably change the maps and hence their consistency with CHIMP data, because at the short periods that control PGA and hence MMI, nonlinear deamplification due to increased soil damping largely offsets linear amplification due to low VS30. Increasing **MMin** reduces but does not eliminate the discrepancy. Inclusion of aleatory variability causes negligible differences in predicted ground motions. We can thus rule out these three effects as causes of discrepancy between predicted and historically observed shaking. We are currently exploring other possible causes.

Keywords: site effects, Vs30, seismic hazard assessment, historical intensity data, California, GMICE

*Speaker
†Corresponding author: mollygallahue2023@u.northwestern.edu

Collisional (Indenter) Tectonics of the Santa Ana Mountains and the Southern Los Angeles Basin, Orange County, California

Eldon Gath * [1]

[1] Earth Consultants International – United States

The Santa Ana Mountains (SAM), a plutonic-cored Mesozoic intrusive body dominating Southern California's Orange County landscape, are being thrust into the sediment-filled Los Angeles Basin at _˜6 mm/yr by the right-lateral Elsinore fault. This SAM indenter has resulted in _˜18 km of northwest-vergent penetration into the Cretaceous to Pleistocene sedimentary section. This in turn has and is generating multiple secondary tectonic geomorphic structures including strike-slip faults, anticlines, imbricate thrust sheets, and disseminated secondary faulting and fracturing of the surrounding rocks. Simultaneously, the south-vergent Puente Hills are uplifting along a blind Puente Hills thrust fault. As these two structures converge, the uplift rate of the Puente Hills is increased, the right-lateral Whittier fault accommodates westward escape tectonics of the basin sediments at 2-3 mm/yr, and 1-2 mm/yr left-lateral shearing is developed within a deformable shale unit along the western SAM margin due to weak coupling of the sedimentary rocks and the plutonic indenter. Microseismicity is concentrated within the deforming sedimentary section above and in front of the indenting pluton, reactivating pre-existing secondary faults and posing a regional ground deformation (and seismic shaking) hazard to the 3+ million people of Orange County, California.

Keywords: Tectonic geomorphology, Seismic hazards, Indenter tectonics

*Speaker

Recurrence period of large earthquakes at the western Alps-Mediteranean sea junction : from geological observations and modeling of the seismicity rate

Christophe Larroque * [1,2], Oona Scotti [3], Françoise Courboulex [4], Jenny Trévisan [5]

[1] Laboratoire Géoazur – Université Côte d'Azur, CNRS, Observatoire de la Côte d'Azur, IRD, Sophia Antipolis 06560 Valbonne, France – France
[2] Laboratoire GEGENAA – Université de Reims Champagne-Ardenne, 51100 Reims, France – France
[3] BERSSIN – Institut de Radioprotection et de Sûreté Nucléaire (IRSN), 92262 Fontenay-aux-Roses cedex, France – France
[4] Laboratoire Géoazur – Université Côte d'Azur, CNRS, Observatoire de la Côte d'Azur, IRD, Sophia Antipolis 06560 Valbonne, France – France
[5] Laboratoire Géoazur – Université Côte d'Azur, CNRS, Observatoire de la Côte d'Azur, IRD, Sophia Antipolis 06560 Valbonne, France – France

In intraplate regions the process that triggers earthquakes has been recently questioned. Earthquakes in such regions could potentially occur as a result of transient stress/strength perturbations (deglaciation, erosion, fluid circulation), releasing elastic energy from a pre-stressed crust rather than due to the localized accrual of tectonic stresses. Were this to be the case everywhere in intraplate regions, probabilistic seismic hazard assessments (PSHA) should also be questioned, since they are based on the assumption that earthquakes have a recurrent nature controlled by far-field tectonic forces. It is therefore paramount to document in which regions classical PSHA approaches can be still considered valid or may need to be revised.
Metropolitan France is an intraplate region characterized by a low to moderate seismic activity where some rare moderate-to-strong earthquakes do also occurr, mostly located in the Alps and in the Pyrenees. The junction between the western Alps and the Mediterranean sea, between Nice and Genoa, suffered such an earthquake (Mw 6.7-6.9) on 23 February 1887 that activated a segment of the Ligurian faults system (LFS). Although since 1887 only one strong earthquake occurred on the LFS, there are historical evidences of repeated earthquakes and geological evidences of long-term (at least 5 Myr) consistent compressive deformation attesting to an active intraplate area.

In this presentation we propose to discuss the recurrence times of 1887-ligurian-type earthquakes along this long-lived compressive tectonic system by (i) estimating slip rates based on GNSS and geologic data and (ii) using the SHERIFS* approach to compute the associated synthetic seismicity rates considering a wide range of hypotheses. Comparison of the resulting synthetic seismicty rates with those computed on the basis of earthquake catalogues (SHARE and LDG) allows then selecting a range of plausible recurrence times for 1887-ligurian-type earthquakes

*Speaker

which are consistent with GNSS, geologic and earthquake catalogue data.

Keywords: seismis hazard, recurrence times, intraplate domain, seismicity rate modelling

Characterization of active faults in intraplate domains: benefits from the use of multi-scale seismic reflection data

Kévin Manchuel *† [1], Sylvain Pouliquen [1], Christophe Vergniault [1], Pierre Arroucau [1], Romain Le Roux-Mallouf [1], Jean-François Ritz [2]

[1] EDF – Electricité de France - EDF : DIPNN-DI-TEGG – France
[2] Geosciences montpellier – Géosciences Montpellier : Univ. Montpellier, CNRS, Univ. Antilles – France

Intraplate domains, located far away from lithospheric plate boundaries, exhibit low deformation and geological deformation velocities and are characterized by low to moderate seismicity with long return period between two significant earthquakes. In these regions, surface processes act faster than tectonics and tend to erase the geomorphological surface rupture evidences produced by large past earthquakes. Faults activity assessment in such contexts requires the implementation of a multi-disciplinary approach that combines geophysics, geology and paleoseismology. We present here the approach putted in place by EDF and its collaborators to improve fault knowledge in metropolitan France for seismic hazard assessment purpose. This approach is based on a progressive focus on tectonic structures, in order to gradually increase the precision of observations with the goal of characterizing faults location, geometry, kinematic history and level of activity. In addition to classic geological, seismological and geomorphological analysis, often not conclusive in stable continental regions, seismic reflection data coming from petroleum exploration are first used when available (if not they are acquired) to constrain location, geometry at depth and long-term kinematic history. Then, subsurface seismic reflection data acquisitions are realized to improve fault location close to the surface and to define paleoseismological trench location to study fault quaternary activity.

Keywords: Intraplate domain, active faults, seismic reflection imagery

*Speaker
†Corresponding author: kevin.manchuel@edf.fr

Impact of variable fault geometries and slip rates on earthquake catalogues from physics-based simulators for the Cape Egmont Fault, New Zealand

Efstratios Delogkos *† [1], Andrew Howell [2,3], Hannu Seebeck [2], Bruce Shaw [4], Andrew Nicol [3], John Walsh [1]

[1] Fault Analysis Group, UCD School of Earth Sciences, University College Dublin, Belfield, Dublin, Ireland – Ireland

[2] Te Pū Ao – GNS Science, Lower Hutt, New Zealand – New Zealand

[3] School of Earth and Environment, University of Canterbury, Christchurch, New Zealand – New Zealand

[4] Lamont Doherty Earth Observatory, Columbia University, Palisades, New York, U.S.A – United States

Physics-based earthquake simulators have been developed to overcome the relatively short duration and incompleteness of historical earthquake and paleoseismic records. Earthquake simulators produce millions of virtual earthquakes over thousands to millions of years using predefined fault geometries, locations and slip rates. Due to the sparsity of geological and/or geodetic data combined with limited computing-power capabilities, it is common to simplify input parameters for earthquake simulators. Typically slip rates are assumed to be uniform and fault surfaces planar from the mapped fault traces (e.g., the intersection of the faults with the Earth's surface). This study uses an exceptionally well-defined 3D geometry of an active normal fault in offshore New Zealand, the Cape Egmont Fault, to demonstrate the impact of using non-uniform slip rates and realistic fault geometries on the resulting virtual earthquakes. Variable slip rates (instead of constant slip rates) can resolve issues associated with intense seismicity at the fault edges and unrealistic distributions of events with increasing depth. Introduction of realistic 3D fault geometries, including fault segmentation and bends, produces less characteristic earthquake populations with lower b-values. Incorporation of variable fault geometries and slip rates in physics-based simulators can generate realistic earthquake catalogues which may have application for seismic hazard models.

Keywords: physics, based simulators, fault geometry, slip rate, Cape Egmont Fault

*Speaker

†Corresponding author: stratos.delogkos@ucd.ie

Fault-based seismic hazard assessment for the city of Guadalajara, Central Mexico

Fabien Ramel * [1], Pierre Lacan† [2], Laurence Audin‡ [3], Ramón Zuniga§ [2], Mario Ordaz¶ [4]

[1] Géosciences Montpellier – Institut National des Sciences de l'Univers : UMR5243, Université de Montpellier, Centre National de la Recherche Scientifique : UMR5243 – France
[2] Centro de Geociencias [Queretaro] – Mexico
[3] Cycle sismique et déformations transitoires – Institut des Sciences de la Terre – France
[4] Instituto de Ingeniería [Mexico] – Mexico

The Trans Mexican Volcanic Belt (TMVB) is an active volcanic arc affected by extensive tectonic deformation along crustal faults. Numerous and poorly characterized, these faults have been the source of several major earthquakes from Mw 6 to Mw 7.2 over the past 500 years. Despite the high population density and the presence of the two largest cities in Mexico within the TMVB (Mexico City and Guadalajara), the estimation of the hazard associated with these faults had never been undertaken until now.

For the last ten years, an effort has been made to better understand and characterize their activity. Several paleoseismological studies have thus been able to highlight long return periods for Mw> 6 earthquakes of 1,000 to 10,000 years and slow slip rates, less than 1 mm/yr. In this context, the classic approach to estimating the hazard from historical and instrumental seismicity catalogs is very likely fruitless.

The probabilistic assessment of the seismic hazard presented here for the West of the TMVB is based on the construction of a source model based on active faults. To overcome the lack of data on faults, a set of assumptions on the geometry and activity of these structures is used and the impact of these choices on the evaluation of the hazard is evaluated.

The accelerations associated with a probability of 10% in 50 years for Guadalajara reach 0.2g and up to 0.4g in certain bordering areas. The associated spectral periods also show that the small structures that make up most of the city's buildings are very vulnerable.
A retrospective analysis of the modeling work is finally used to discuss the additional studies necessary to improve the model. A better characterization of segmentation, slip rates and seismogenic depth appears urgent in this densely populated area of Latin America for a better hazard assessment.

*Speaker
†Corresponding author: placan@geociencias.unam.mx
‡Corresponding author: Laurence.Audin@ird.fr
§Corresponding author: ramon@geociencias.unam.mx
¶Corresponding author: MOrdazS@iingen.unam.mx

Keywords: Trans Mexican Volcanic Belt, Mexico, Probabilistic Seismic Hazard Assesment, crustal faults

Identification and measurement of the co-seismic fault offset along the North Anatolian Fault in the Central Basin through the co-seismic sedimentary episodes

Corina Campos * [1], Christian Beck [2], Oswaldo Guzman [3]

[1] Grupo de Ciencias de La Tierra y Clima. Universidad Regional Amazónica Ikiam. Ingeniería en Geociencias. – Ecuador
[2] Laboratoire ISTerre, UMR CNRS 5275, Université de Savoie/Grenoble-Alpes University, 73376 Le Bourget du Lac, France – Université de Savoie – France
[3] Grupo de Ciencias de La Tierra y Clima. Universidad Regional Amazónica Ikiam, Ecuador – Ecuador

In the deep part of the Sea of Marmara, Turkey, the sedimentation developing upon the North Anatolian Fault is strongly influenced by the associated seismic activity, through gravity reworking (fluidized landslides) and tsunamis. Specific layers named homogenites + turbidites (HmTu) representing individual sedimentary events, have been characterized along three giant piston cores retrieved from the Çinarcik and Central (or Orta) basins. They are the results of re-depositional processes, which may result into specific complex layers, due to reflections on steep slopes and/or to oscillations of the whole water mass (reflected tsunami, seiche effect). The main characteristics of these sedimentary deposits are: i) a sharp limit at the top of a coarse graded lower part, ii) a structureless highly homogenous fine grained upper part. In the present work, Pre-Holocene non- marine sediments were analyzed, representing the last 12 to17 kyr BP. For a 2 kyr long interval, 11 events could be precisely correlated on both sides of the Central Basin's southwestern scarp. For each of them, based on the specific depositional process, the thickness difference between the two sites was considered as a direct estimation of the vertical component of a coeval coseismic offset. The homogenite (upper) component accounts for the major part of the thickness difference (ranging from 36 to 144 cm). These offsets were considered as likely representing dominantly vertical throws, along the transtensional southwestern boundary of the inner, pull-apart Central Basin.

Keywords: co, seismic fault offset, Homogenites, Turbidites, Marmara, Turkey

*Speaker

Probabilistic assessment of the seismic source of subaqueous mass transport deposits, with application to Aysén Fjord, southern Chile

Kris Vanneste *† [1], Katleen Wils [2], Maarten Van Daele [2]

[1] Royal Observatory of Belgium – Belgium
[2] Renard Centre of Marine Geology (RCMG), Department of Geology, Ghent University, Ghent – Belgium

Paleoseismic studies of mass transport deposits (MTDs) in lakes and fjords have proven invaluable to reconstruct the shaking history of the surrounding region. However, because these deposits are usually not connected to a fault rupture, assessment of the earthquake source remains challenging. Based on simultaneous observations of coseismic mass wasting and seismic shaking, it is possible to assign intensity thresholds for the occurrence or absence of different MTD types. Previous studies to estimate the source location and magnitude from the spatial distribution of MTDs used methods for traditional macroseismic data, involving the reverse application of intensity prediction equations (IPEs) in combination with a grid search. A shortcoming of this method is that the assigned intensity thresholds are considered as fixed intensities. To overcome this drawback, we developed an approach based on the principles of probabilistic seismic hazard assessment and ground-motion modelling. This allows the triggering intensity to exceed the assumed threshold, considers negative evidence the same as positive evidence, and also takes into account IPE uncertainties. It can be applied in combination with a grid search, but we further improved it by considering known active faults. We apply the probabilistic method to Aysén Fjord, which has been affected by both megathrust and crustal earthquakes. The latter originate from the Liquiñe-Ofqui Fault Zone (LOFZ), a strike-slip fault system intersecting the fjord. In 2007, an MW=6.2 earthquake on one of these faults caused intensities of VIII+ and major landslides entering the fjord. The sedimentary fill contains nine older MTD levels, at least five of which in the Holocene. Our results confirm that most MTDs can be attributed to earthquakes on the LOFZ, in addition to at least two megathrust earthquakes. The method thus has great potential to constrain the size and location of paleoearthquakes for which only shaking evidence is available.

Keywords: seismic source, probabilistic, shaking evidence, lacustrine, fault network, intensity prediction equation

*Speaker
†Corresponding author: kris.vanneste@oma.be

Magnitude 9 along the Himalayan arc during the medieval period ?

Romain Le Roux-Mallouf * [1], Pierre Sabatier [2], Christian Crouzet [3], Jérôme Nomade [4], Manon Bajard [5], Peter Van Der Beek [6]

[1] EDF-DI-DIPNN-TEGG – EDF – DIPNN - CEIDRE - TEGG - SGG, EDF – DIPNN, Aix-en-Provence, France – France

[2] EDYTEM – Université Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, EDYTEM, 73000 Chambéry, France – France

[3] ISTerre – Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, IRD, IFSTTAR, ISTerre, 38000 Grenoble, France – France

[4] ISTerre – Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, IRD, IFSTTAR, ISTerre, 38000 Grenoble, France – France

[5] EDYTEM – Université Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, EDYTEM, 73000 Chambéry, France – France

[6] Institute of Geosciences, Potsdam University – Germany

The existence of lateral variations in crustal structures along the Himalayan arc is now well-established but their role on the stress builds up along the Main Himalayan Thrust and their influence on the magnitude on large Himalayan earthquakes are still debated. Paleoseismological works carried out from Central Nepal to Arunachal Pradesh reveal that eastern Himalaya has been struck by 8 to 13 meters vertical slip great earthquake and support the occurrence of either a Mw9 earthquake or a sequence of great earthquakes along the Himalayan arc during a period ranging from AD 1025 to AD 1547. Here, we address this issue using a new record of earthquake-triggered turbidites from Lake Jimilang in central Bhutan. The lake sediment records both 29 events related to Himalayan earthquakes and two large earthquake-triggered turbidites induced by previously reported Mw 8 earthquake in Bhutan. The penultimate large event is now well dated at 1354 $\pm$ 47 AD and no longer corresponds to the Middle age earthquake in Nepal. This observation supporting the sequence hypothesis with a series of great single-segment earthquake during a medieval period in central and eastern Himalaya.

Keywords: Palaoseismology, Earthquake catalog, Himalaya, rupture characteristics of past earthquakes

*Speaker

Outreach on Earthquake Geology as a tool to increase social seismic awareness

María Ortuño * [1], Eulàlia Masana [1], Raimon Pallàs [1], Octavi Gómez-Novell [2], Marta Ferrater [3], Jaume Bordonau [1]

[1] University of Barcelona – Spain
[2] Univ. Chieti-Pescara – Italy
[3] Secondary School Manuel de Cabanyes, Vilanova – Spain

One of the factors that hinders the social identification of seismic risk in many regions is the long-elapsed time span since the last destructive event, which is especially common in moderate and slow deformation areas. We propose to strengthen the use of outreach tools in Earthquake Geology to attract the attention of the population towards seismic risk exposure, especially among children. We present an outreach short-film on Earthquake geology ("Earthquake land", available in YouTube), and provide three classroom activities to: 1) introduce the concepts of Plate tectonics and tectonic blocks with the help of large puzzles; 2) explore the seismic cycle by reproducing the cumulative changes imprinted in the landscape by repetitive fault movements (and consecutive earthquakes) and; 3) reproduce the effects of wave amplification in sedimentary infills through the "amplification pie". The effectiveness of the activities is being tested in several schools in Catalonia. We aim to improve seismic education by incorporating the suggestions of young participants (subjects of the experiences), who evolve from passive recipients to main actors in the prevention strategy.

Keywords: Earthquakes, Social impact, Education

*Speaker

Characteristics of secondary (distributed) ruptures of normal and reverse surface faulting earthquakes: implications for fault displacement hazard analysis

Paolo Boncio * [1], Francesco Visini [2], Stéphane Baize [3], Fiia Nurminen [4], Bruno Pace [1], Oona Scotti [5]

[1] Department of Engineering and Geology, Università "G. D'Annunzio" Chieti-Pescara, Chieti, 66100, Italy – Italy
[2] Istituto Nazionale di Geofisica e Vulcanologia (INGV) – Via di Vigna Murata 605, 00143 Roma, Italy
[3] Institut de Radioprotection et de Sûreté Nucléaire – Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – France
[4] Università "G. D'Annunzio" Chieti-Pescara, Chieti, 66100, Italy – Italy
[5] Institut de radioprotection et de sûreté nucléaire (IRSN) – Ministère de l'écologie de l'Energie, du Développement durable et de l'Aménagement du territoire, Ministère de la santé, Ministère de la Défense, Ministère de l'Enseignement Supérieur et de la Recherche Scientifique, Ministère de l'économie, de l'industrie et de l'emploi – IRSN/BERSSIN, BP 17, 92262 Fontenay-aux-Roses Cedex, France

During surface faulting earthquakes, displacement on secondary faults or factures may occur off the trace of the principal fault (PF), in the vicinity of the PF or up to many kilometres away. They are called distributed ruptures (DR). Though DRs are discontinuous in nature and characterized by lesser amount of displacement compared to the PF, their occurrence may threaten structures the safety and functionality of which are sensible to low levels of permanent ground displacement, such as critical infrastructure. Often DRs occur in unpredictable locations, without previous geologic evidence, making the assessment of fault displacement hazard from DR challenging. In this work we explore the characteristic of DRs from the analysis of numerous historical reverse and normal surface ruptures contained in a new release of the 'SUrface Ruptures due to Earthquake (SURE)' database (SURE 2.0, Nurminen et al,. submitted). The database contains slip measurements and mapped traces of 50 historical surface ruptures of global, dip-slip and strike-slip earthquakes occurred between 1872 and 2019. The novelty of the SURE 2.0 database compared to the previous version is a ranking scheme which categorize the ruptures on the basis of geological information. In this work we analyse the distance-frequency and displacement distributions 34 reverse and normal events using the ranking information. The results have implications for deriving regressions that can be used in probabilistic analysis of fault displacement hazard.

Keywords: Fault displacement hazard analysis, distributed surface faulting, dip slip earthquakes

*Speaker

Impact of far-field glacially induced stresses on fault stability in the eastern Paris basin

Adrien Damon *† [1,2], Stéphane Mazzotti [2], Philippe Vernant [2], Rémi Vachon [3], Juliette Grosset [2], Frédéric Ego [1], David Baumont [4]

[1] ANDRA, 7, rue Jean-Monnet, 92298 Châtenay-Malabry cedex, France – ANDRA – France
[2] Géosciences Montpellier, CNRS, Université de Montpellier, 34000 Montpellier, France – Centre National de la Recherche Scientifique : UMR5243, Université de Montpellier – France
[3] Department of Earth Sciences (MPT), Geocentrum, Villavägen 16, 752 36 Uppsala – Sweden
[4] Seister S.A.S., Immeuble Le Quartz, 58 chemin de la justice, 92290 Châtenay-Malabry, France – Seister – France

We investigate the impact of stress perturbations induced by GIA (Glacial Isostatic Adjustment from Fennoscandian, Alpine & Massif Central ice systems) on the stability of inherited faults in the Paris Basin. The stable continental region (SCR) of the Paris Basin (PB) is nowadays a very low seismicity region (few earthquakes with M< 4), yet GNSS strain rates show that there is active deformation in and around the PB. Active deformation, potentially linked to GIA, is observed in other SCR (e.g. Scandinavia, Eastern Canada) and may be linked to large earthquakes of M> 6.
We use numerical modeling to estimate the far-field visco-elastic deformation of the PB lithosphere under Last Glacial Maximum (LGM) ice loading and unloading. Three deformation scenarios are selected for their representativity of the results' variability based on a parametric study of the lithosphere rheology variations (expressed as Equivalent Elastic Thickness, EET). Results are calculated for synthetic faults of 0-360○N azimuth and 60-90○ dip, for both LGM and present-day.
The predicted CFS show variability associated with EET estimates and timing. Nonetheless, assuming the existence of optimally oriented 60-90○ dipping faults in a critically stressed lithosphere, preliminary CFS calculations suggest that the rupture of pre-existing normal and strike-slip faults could be promoted due to GIA stress perturbations by the LGM, as well as nowadays with a lesser amplitude. Furthermore, CFS modeling suggests that a few major known faults in the PB could also be favorably oriented with respect to GIA stress perturbations even if, on the other hand, last movements estimated on these faults are estimated to Miocene or older. The impact of ambient PB stress field anisotropy on CFS estimates will next be tested. To complete our models, the impact of erosion/deposition in and around the PB on lithosphere deformation and fault stability will also be studied.

Keywords: Seismotectonics, glacial isostasy, fault reactivation, stable continental region, Paris Basin

*Speaker
†Corresponding author: adrien.damon@umontpellier.fr

Speleoseismology as a tool to validate and constrain seismic hazard models: examples from Central and Southern Apennines in Italy.

Bruno Pace *† [1], Luigi Ferranti [2], Alessandro Valentini [3]

[1] Department of Engineering and Geology, Università "G. D'Annunzio" Chieti-Pescara, Chieti, 66100, Italy – Italy
[2] DiSTAR - Dipartimento di Scienze della Terra, dell'Ambiente e delle Risorse Università di Napoli "Federico II" – Italy
[3] Università degli studi "Gabriele d'Annunzio", Chieti-Pescara, Italy – Italy

In the last thirty years, speleothems have become excellent tools for paleoenvironmental and paleoclimatic reconstructions of the Quaternary. Recently, in addition to these kinds of studies, an important scientific application regards speleoseismological reconstructions. In particular, it has been argued that natural speleothems could give important constraints on seismic hazard estimates since they have survived all the earthquakes over their life span. The underlying idea is based on the stalactite-stalagmite oscillatory system, which represents the vertical datum. The deviation of the growth axis from the vertical, and the speleothem breakage, could be evidence for shaking of the cave walls, excluding the possibility of other of deformation sources (landslide, flooding, ice flow, animal or anthropic passage). However, the difficulty in quantitative modelling of the observed deformation, and its direct attribution to a seismogenic source remains a major issue. In this work we present speleoseismological studies carried out in the Pollino Range (Calabria, southern Italy) and in Central Apennines (Abruzzo, central Italy), where we used the speleothems data to validate and improve the seismogenic sources models and the fault-based probabilistic seismic hazard estimates. In the first case-study the results highlight that a speleoseismological approach can be fruitfully applied in regions with low active tectonic rates and with caves where both the record of speleoseismic events and fragile intact speleothems are present. In the second case-study, the collapse of a massive speleothem permitted to establish whether this collapse can be considered as the record of a large paleoearthquake occurred in the past, and a fault-based seismic hazard model together with a numerical modelling allowed to define the possible source responsible of the collapse. Because on-fault trenching is not always possible, the proposed approaches integrate information on activity for faults in various tectonic context.

Keywords: Speleoseismology, Seismic Hazard, Active Tectonics, Apennines

*Speaker
†Corresponding author: bruno.pace@unich.it

The Tien Shan Active Fault Database; a new collaborative compilation for multi-use purposes

Tamarah King *† [1], Austin Elliott [2], Richard Walker [3], Christoph Gruetzner [4]

[1] COMET, Department of Earth Sciences, Oxford – United Kingdom
[2] United States Geological Survey – United States
[3] COMET, Department of Earth Sciences, Oxford – United Kingdom
[4] University of Jena – Germany

We present version 1.0 of our Tien Shan Active Fault Database which collates faults across Central Asia, largely covering Kyrgyzstan and Kazakhstan. This database integrates decades of mapping and field-studies by researchers from the UK NERC Centre for Observation and Modelling of Earthquakes, Volcanoes and Tectonics (COMET) with in-country experts and collaborators from global institutes. Fault databases are primary inputs to many seismic hazard models and modellers rely on database compliers (generally geologists) to produce accurate and meaningful representations of fault locations, geometries, activity rates and kinematics. However, resolution and accuracy of fault mapping varies between practitioners and mapping purpose, with inherent biases that can impact hazard outputs. This database incorporates mapping from a range of contributors and aims to both standardize representation and acknowledge bias wherever it cannot be reduced. We retain complexity, avoid over-interpretation beyond what original mappers produced, and reduce tedious manual line revisions by implementing a three-tiered database structure. These levels represent variable resolutions (scales) of fault line-mapping for various purposes and are modified based on the recent "Fault2SHA Central Apennines database". Version 1.0 of the database is primarily concerned with mapping the locations of active faults across these levels, while future editions will incorporate necessary metadata for the faults.

Keywords: Fault database, Central Asia, Tien Shan, active faults

*Speaker
†Corresponding author: tamarah.king@earth.ox.ac.uk

An updated seismogenic source model for seismic hazard assessment in the northern Andes

Ana María Tobón López *† [1], Laurence Audin [2], Céline Beauval [3], Stéphane Baize [4]

[1] Cycle sismique et déformations transitoires @ Institut des sciences de la Terre – Université Grenoble Alpes BP 53 38041 Grenoble cedex 9 - France – France
[2] Institut des sciences de la Terre (ISTerre) – OSUG, INSU, Université Joseph Fourier - Grenoble I, Université de Savoie, IFSTTAR, IRD, CNRS : UMR5275 – BP 53 38041 Grenoble cedex 9, France
[3] Institut des sciences de la Terre (ISTerre) – CNRS : UMR5275, IFSTTAR, IFSTTAR-GERS, Université de Savoie, Université Joseph Fourier - Grenoble I, INSU, OSUG, Institut de recherche pour le développement [IRD] : UR219, PRES Université de Grenoble – BP 53 38041 Grenoble cedex 9, France
[4] Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – Institut de Radioprotection et de Sûreté Nucléaire (IRSN) – BP17 92262 Fontenay-aux-Roses Cedex, France

Colombia represents one of the most complex tectonic and geodynamic settings in South America, hosting the long-lasting subduction of the Caribbean and the Nazca plates beneath northwestern South America. The million-year-long interaction of multiple slabs and accreted terranes along the continental margin of South America has driven various tectonic events and changes in crustal deformation over time. The increasing number of research projects and publications are bringing up new models and enriched datasets that highlight novel details on regional geodynamics and plate kinematics. Therefore, we propose revisiting the seismic hazard model for Colombia, using an updated earthquake catalogue with events from 1610 to 2020, active fault compilations and recent geophysical, seismologic and geodetic datasets to delineate seismogenic source zones (SSZ) that include faults. The integration of new datasets reveals features that have not been considered previously for recognized SSZs. For example, we propose a geometry for the transition between the Nazca and Caribbean plates and we analyze the interaction of the Panama arc with the shallow crust. We document the criteria to define the SSZ boundaries (for subduction and the crustal domain) and the uncertainties associated with the decisions. In addition, we consider the variability of the seismogenic layer to constrain the depth of each SSZ. Because several active faults have been identified, we will use a combination of areal and fault sources for PSHA modelling at the regional scale. We explore the earthquake recurrence based on earthquake rates, integrating the available long term (Quaternary) and short term (geodetic) deformation rates associated with each SSZ. A special effort is led to harmonize the data across country boundaries (Ecuador, Venezuela, Panama) from local to continental scale. As a perspective, we plan to couple this new SSZ model with ground-motion models to estimate probabilistic seismic hazard at the scale of the country.

*Speaker
†Corresponding author: ana-maria.tobon-lopez@univ-grenoble-alpes.fr

Keywords: seismotectonics, South America, active faults, crustal deformation, seismogenic source zones, probabilistic seismic hazard, Colombia

List of participants

- Alvarado Alexandra
- Alvarellos Victoria
- Andrews Billy
- Arora Shreya
- Arrowsmith Ramon
- Audin Laurence
- Azuma Takashi
- Baize Stéphane
- Banjan Mathilde
- Benites Belén
- Bollinger Laurent
- Boncio Paolo
- Braun Anika
- Buck Jason
- Campos Corina
- Cathelin Nicolas
- Cheon Youngbeom
- Choi Yire
- Choi Jin-Hyuck
- Cornejo Carolina
- Damon Adrien
- De Pascale Gregory
- De Sigoyer Julia
- Debaecker Sophie
- Delogkos Efstratios

- Diercks Manuel
- Duperret Anne
- Easton Gabriel
- Ferranti Luigi
- Ferry Matthieu
- Figueiredo Paula
- Gaidzik Krzysztof
- Gallahue Molly
- Gath Eldon
- Gómez-Novell Octavi
- González-Alfaro José
- Gruetzner Christoph
- Guzman Oswaldo
- Gwon Ohsang
- Han Long Fei
- Harrichhausen Nicolas
- Henriquet Maxime
- Henry Pierre
- Iezzi Francesco
- Jomard Hervé
- Kaci Tassadit
- Kázmér Miklós
- Kim Dong-Eun
- Kim Chang-Min
- Kim Taehyung
- Kim Young-Seog
- Klinger Yann
- Koehler Rich
- Larroque Christophe
- Le Roux-Mallouf Romain
- Leclerc Frederique
- Lee Hoil

- Lefevre Marthe
- Lei Shengxue
- Livio Franz
- Lomax Anthony
- Losen Julie
- Manchuel Kevin
- Marco Shmulik
- Marconato Léo
- Marliyani Gayatri
- Marshall Neill
- Maslač Josipa
- Matrau Remi
- Mccalpin James
- Melnick Daniel
- Meriaux Anne-Sophie
- Mildon Zoe
- Molins Vigatà Júlia
- Montabert Arnaud
- Naik Sambit Prasanajit
- Niemi Tina
- Ollé Marc
- Onderdonk Nate
- Ortuño María
- Pace Bruno
- Palagonia Sylvain
- Pamumpuni Astyka
- Park Kiwoong
- Patton Jason
- Perea Manera Hector
- Perrin Clément
- Pierce Ian
- Pinzon Matapi Nicolas

- Pizza Marco
- Poursoulis Georgia
- Pousse Lea
- Ramel Fabien
- Ramírez-Herrera María-Teresa
- Reicherter Klaus
- Riesner Magali
- Ritz Jean-Francois
- Rizza Magali
- Rockwell Thomas
- Rodriguez Piceda Constanza
- Scotti Oona
- Srivastava Eshaan
- Sue Christian
- Szczygieł Jacek
- Tamarah King
- Testa Alessio
- Thomasset Camille
- Tobón-López Ana María
- Tringali Giorgio
- Tsai Chia-Hsin (wendy)
- Van Der Woerd Jerome
- Vanneste Kris
- Vassallo Riccardo
- Vega Ruiz Ambrosio
- Victor Pia
- Walker Richard
- Whitney Beau
- Štěpančíková Petra

List of sponsors

CNRS
Centre National de la Recherche Scientifique

CEREGE
Centre Européen de Recherche et d'Enseignement de Géosciences de l'Environnement

Institut de Radioprotection et Sûreté Nucléaire
IRSN, a public expert with industrial and commercial activities, was set up in 2001. ?The Institute is supervised jointly by the French Minister of the Ecological transition, the French Minister of Defense, and the French Ministers of Energy transition, Research and Health. It is the nation's public service expert in nuclear and radiation risks, and its activities cover all the related scientific and technical issues.

International Union For Quaternary Research
The TPPT (n° 2008F TPPT) and EDITH (n° 2009P) Projects of INQUA contribute to the Early-career reseachers participation to this conference

UNESCO - Project IGCP-669

OLLIN: Identification of seismogenic faults in populated areas of Latin America and its incorporation into seismic hazard assessment

Géoazur

Géoazur Laboratory is a multidisciplinary joint research unit comprising geophysicists, geologists, and astronomers working on crucial scientific issues such as: telluric hazards – seismic, gravitational and tsunamigenic events – and related risks; lithosphere dynamics and Earth imaging; geodesy and metrology of the Earth and the nearby universe... The laboratory is part of Observatoire de la Côte d'Azur, and Université Côte d'Azur, and IRD

Institut de physique du globe de Paris

IPGP is a research institute dedicated to Earth Sciences. It is a member of Université de Paris Cité and it is related to CNRS, IGN, CNES and University of la Réunion. The institute includes about 150 full time researchers and about the same number of PhD candidates and post-doctoral fellows. IPGP conducts research in a broad variety of topics, from solid earth to planetary sciences and environmental related issues.

EDF

Electricité de France

RESIF

The French seismological and geodetic network Résif-Epos is a research infrastructure that deploys modern instrumentation (seismometers, GNSS stations and gravimeters) in metropolitan France to measure the deformation of the Earth's surface. The data collected allow us to understand the dynamics of the internal Earth, its natural and anthropogenic hazards, and its interactions with the atmosphere and the ocean.

CEA, Commissariat à l'énergie atomique et aux énergies alternatives
Le CEA est un organisme public de recherche à caractère scientifique, technique et industriel. Acteur de la recherche, du développement et de l'innovation, le CEA intervient dans les domaines de la défense et la sécurité, les énergies bas carbone (nucléaire et renouvelalbes), la recherche technologique pour l'industrie et la recherche fondamentale (sciences de la matière et sciences de la vie).

Aix-Marseille Université
Aix-Marseille Université

IRD
Institut de Recherche et Développement

OCA
Observatoire de la Côte d'Azur

UCA
Université Côte d'Azur

Author Index