

6th Colloquium on historical earthquakes & paleoseismology studies

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Han-sur-Lesse

Book of Abstracts

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Introduction to the Colloquium

Session 2.2 / 6

Assessing Holocene tsunamigenic subduction earthquakes in the Northern Chile Seismic Gap and their effects on human occupations. Lessons from the past for the future

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The subduction margin of the Central Andes is characterized by the occurrence of large earthquakes associated with the convergence of the Nazca and South American Plates at about 6.5-7.0 cm/yr (DeMets et al., 1994; Angermann et al., 1999; Béjar-Pizarro et al., 2010). This convergence rate is responsible for causing giant tsunamigenic subduction earthquakes like the 1868 Mw 8.8 and 1877 Mw 8.8 events that affected vast areas along southern Peru and northern Chile (Kausel, 1986; Dorbath et al., 1990; Comte and Pardo, 1991; Fig. 1). In particular, the last giant earthquake in 1877 ruptured ~450-500 km along northern Chile, producing tsunami waves of up to 20 meters in the epicentral area (Kausel, 1986; Comte y Pardo, 1991), but that equally impacted neighbouring coastal areas. Today, northern Chile is considered a mature seismic gap (Kelleher, 1972; Nishenko, 1985; Kausel, 1986). Unfortunately, the historical seismic record of the region is only two hundred years long (Comte and Pardo, 1991), and the hyperarid and rocky landscape of most coastal areas have hindered systematic paleoseismological research on the coastal platform. Therefore, our knowledge about earthquake occurrence along this hyperarid subduction margin is still very limited. In this paper we present results of an interdisciplinary research aiming to fill this gap by identifying Holocene tsunamigenic subduction earthquakes along the coast of northern Chile, and their effects on prehistoric human populations. Our research has combined different approaches to the geological, geomorphological, archaeological and historical records. Our results indicate the occurrence of tsunamigenic megaeearthquakes of different intensities at 500 BP, 950 BP, 1300 BP, 1500 BP and 4000 BP. The latter date coincides with major transformations in human demography and local settlement systems, suggesting causal links between catastrophic events and historical change. This discovery may have significant implications for the understanding of cultural changes/adaptation in relation to extreme natural disasters, and for seismic and tsunami hazard assessment in the present.

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Probabilistic evaluation of the fault source of coseismic mass-transport deposits: the example of Aysén fjord, Chile

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Contemporaneous mass transport deposits (MTDs) recorded in high-resolution sediment archives provide evidence of past seismic shaking. However, because they usually cannot be linked directly to a fault rupture, assessment of the earthquake source (location and magnitude or specific

fault) based on this type of indirect paleoseismological evidence remains difficult. Based on observations of coseismic mass wasting and associated seismic intensities, previous studies have assigned minimum shaking levels required to trigger them. Attempts to infer the most likely earthquake source mostly relied on methods originally developed to estimate the location and magnitude of historical earthquakes using intensity prediction equations (IPEs), but considered these minimum intensities as actual intensity values. Here, we develop a probabilistic method to infer the most likely earthquake source from the spatial distribution of positive and negative MTD evidence. This approach simultaneously allows the triggering intensity to be higher (or lower) than the assumed threshold and takes into account IPE uncertainties, two shortcomings of existing methods. The method is extended by considering known active faults rather than a grid of possible epicenters. We apply this method to Aysén Fjord (southern Chile), which is intersected by strike-slip faults of the Liquiñe-Ofqui Fault Zone (LOFZ). In 2007, an MW=6.2 earthquake hit the fjord with intensities of VIII+, causing major landslides entering the fjord. Seismic reflection profiles show that its sedimentary fill contains a record of nine prehistoric MTDs, which are mainly attributed to crustal earthquakes on the LOFZ. First, we conduct a sensitivity analysis to evaluate the potential of the fjord to distinguish between different possible fault ruptures and to determine which IPE performs best. Application to the MTD record allows identifying the most likely fault sections and magnitude range for most of the events. Compared to methods currently in use, the probabilistic method performs at least as good, and in several cases significantly better. We conclude that the method has great potential to constrain the size and location of paleoearthquakes for which only shaking evidence is available.

Poster Session 1 / 8

RESULTS OF ARCHEOSISMOLOGY IN MEXICO: THE MITLA LAND SLIDE, OAXACA

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The Oaxaca valley was one of the sites with more development in prehispanic cultures, highlighting Monte Alban that has been the most important site of the Zapotec culture. However, this great advance in Mesoamerica, the geological scenario makes the Oaxaca state is vulnerable with seismic activity, as the recent earthquakes of 2017 (Mw8.2) and 2018 (Mw7.2) showed. In the past, different events have been reported, standing out those of 1899 (M8.4) 1903 (M8.2) and 1928 (8.0). This activity is the product of the subduction of the Cocos Plate under the North American plate, inside this last one there are great faults associated with the central valleys of Oaxaca, where the Zapotec and part of the Mixtec cultures were established with the constructions of Monte Alban (500 BC-750 AD) and Mitla (950 AD to 1521 AD). Geologically the prehispanic population of Mitla is located in a NW-SE normal fault valley with slight left components and that to the north constitute the regional structure called Oaxaca-Tehuacán fault. These structures displace the Precambrian and Paleozoic rocks of the Oaxaca and Zapoteco terrains, sometimes covered with Mesozoic sedimentary rocks or, as in the case of Mitla, covered by large packages of Miocene pyroclastic products (ignimbrite, 14Ma). Morphologically, the normal NW-SE fault that generates the Mitla valleys stands out and, together with the seismic activity, generated two major collapses that former spectacular avalanche deposits. In this work we will present the Mitla avalanche, that having been generated by an earthquake at a time not yet established but that could be related to a possible great disaster in the prehispanic population of Mitla, (Mitla means “place of dead” or “large burials”). With the avalanche data we can establish that the ratio of H / L is 0.547, its area of 19,132 m² and its volume of 0.546km³.

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Analysis of deformed speleothems from the Niedźwiedzia Cave in Kletno (Sudetes) - marks of the paleoseismic activity of the Sudetic Marginal Fault?

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In the extensive parts of the Niedźwiedzia Cave in Kletno discovered in 2011-2013, several dozen broken and fallen stalagmites, stalactites and flowstones have been documented, the largest of which are nearly 0.6 m in diameter and ~ 2 m in height. Damaged speleothems can be observed in the whole cave, as well as collapses of thickness up to several meters. In order to decipher the causes of these damages, the structural plan of the cave with particular reference to faults and map of damages were prepared. Samples of damaged speleothems were collected to determine the time interval in which the deformation took place by dating the youngest layer of the broken speleothem and the oldest layer of regrown one. In total 16 samples were taken from 8 sites. Miscellaneous possible causes may result in macroscopically similar deformations: ice creeping, freezing, compaction or liquefaction of clastic deposits underlying speleothems, seismic activity, or just gravity movements. However, the amount and size of the speleothems deformation in the Niedźwiedzia Cave and their superposition within clastic, auto- and allochthonous sediments suggests strong linkage of deformations with the phenomena affecting the entire cave, i.e. tremor or gravitational collapse of the cave. Creeping ice and the accompanying frost should also be considered. The Sudetes seismic activity, combined with faults documented in the cave of possible Alpine origin, as well as the time intervals when the damage occurred, lead us to propose the seismic hypothesis as the primary genetic factor. The seismic hypothesis is supported by the oldest deformations, which occurred around 320-310 ka, i.e. in the warm Pleistocene period (MIS 9). The most intense deformations in the cave, including the massive collapse in the Mastodont Chamber, occurred between ~ 170-155 ka, i.e. the cold Pleistocene phase (MIS 6). However, the mere fact of the speleothems growth at this period suggests that there should not be massive amounts of ice inside the cave. Assuming the hypothesis that local earthquakes led to speleothems and passages deformation in the Niedźwiedzia Cave at least a few different source areas could be considered. According to the interpretation of structural data from the cave, first ground shaking seismic zone could be indicated to the west, to be linked with a fault zone limiting the Upper Nysa Kłodzka Graben. Another active zone may be considered in the north, the one associated with the eastern termination of the Hronov-Poříčí fault zone. At the same time, a strong tremor within the Sudetic Marginal Fault located about 20 km towards NE cannot be unequivocally discarded, since this is one of the most important tectonic lines in this part of Central Europe nowadays, noteworthy with documented neotectonic activity.

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Methodological comparison of macroseismic magnitude estimates for events along the French-Italian border

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Magnitude estimates of earthquakes occurred before the instrumental period are a key issue in seismic hazard assessment. For such earthquakes, the only information available is provided by historical sources. These are first translated into macroseismic intensity by means of intensity scales and then intensities are used to estimate earthquake parameters such as epicentral intensity, magnitude and sometimes depth. Methods for computing earthquake parameters from intensity data differ within and between countries, leading to the long-lasting discussions about the reference earthquake catalogue that should be used for seismic hazard

assessment. Within the SHARE project (<http://www.share-eu.org/>), the SHEEC 1000-1899 catalogue (<https://www.emidius.eu/SHEEC/>; Stucchi et al., 2013) first attempted at homogenizing data and procedures for the assessment of the parameters of historical earthquakes. However some issues remained open, including the way depth is taken into account in the methodology and the way uncertainty is quantified. We compare two methods, Boxer (Gasperini et al 2010) and Quake-MD (Provost and Scotti, 2017) applied to a set of 62 events located along the French-Italian border using the same macroseismic data (SisFrance database, <http://www.sisfrance.net>) and epicentral location. In Boxer parameter estimates result from the application of a single intensity prediction equation (IPE) to each isoseismal. The final estimate is the mean of the magnitudes associated to each isoseismal. The standard deviation of the mean depends on the weight given to each isoseismal, which in turn, depends on the number of data for the given event as well as the number of data used in the IPE calibration procedure for the given intensity class and its associated standard deviation. In the Quake-MD method, on the other hand, several IPEs are calibrated in order to fit the intensity decrease with distance and applied through a least-squares procedure that results in a solution for each IPE with an associated standard deviation. A space of acceptable solutions is then defined for each IPE by rejecting magnitude-depth solutions that are incompatible with the allowed epicentral intensity values and the given IPE. The sum of the acceptable solutions quantifies the epistemic uncertainty of the earthquake parameters in the Magnitude-Depth-Epicentral Intensity space. We show that the treatment of depth has a major impact on magnitude estimates. We compared the barycenter of the Quake-MD space of solutions and Boxer magnitude estimates. Boxer does not assess depth; whereas in the Quake-MD method depth is inverted. In order to quantify differences between the two methods we run a first test assuming that depth is fixed at 10 km depth. In this case, application of the two methods to the 62 macroseismic data sets lead to differences between magnitude estimates characterized by a mean of 0.02 and a standard deviation of 0.26 with only 6% of the events presenting a difference in magnitude estimates greater than 0.5. We then ran a second test for the Quake-MD methodology, where depth can be inverted for and is allowed to range between 1 and 25 km. In this case differences in magnitude estimates are characterized by a mean of 0.05 and a standard deviation of 0.4. In order to understand the statistical significance of such differences, we compared quantified uncertainties using both methodologies. The space of acceptable solutions resulting from the Quake-MD method can be quite large compared to the uncertainty estimates proposed by Boxer. For the first test case we show that 92% Boxer mean magnitude estimates fall within the space of solutions proposed by the Quake-MD methodology. This work underlines the importance of quantifying uncertainties in parametric earthquake catalogues and the need to propagate such uncertainties in seismic hazard assessments, be it probabilistic or deterministic.

Session 1 / 11

Paleoseismological, historical and instrumental databases to be used in seismic hazard assessment of Bangladesh

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Different geo-hazards are investigated in the framework of the German-Bangladesh technical cooperation project: “Geo Information for Urban Planning and Adaptation to Climate Change (GPAC)”. Seismic hazard assessment is one focus of the project. Bangladesh is located close to the boundaries of the complex convergence of Indian and Eurasian plates to the north and to the east. These collision and subduction processes have caused large historical earthquakes also intraplate in Bangladesh (e.g.: 1885 Bengal Earthquake M7 and 1918 Srimangal Earthquake M7.6). Therefore, it is crucial to assess seismic hazard which then will be considered in urban planning of Bangladesh. Compilations of faults derived from classical tectonic analyses indicate that most of the active faults are located in the northern and eastern boundaries of Bangladesh as expected. The recurrence parameters and maximum magnitudes of some of the active faults are derived by paleoseismic investigations. Like in other countries, the earthquake catalog of Bangladesh is structured according to the use of modern instruments from 1963, the use of early instrumentation from 1900 on and collections of historical macro-seismic data. However, due to the sparse seismic network with only few stations on deep sedimentary basins, the detection threshold for intraplate seismic events is high compared to regions like Europe or China. Also

only few historical seismic events were documented before 1900. Hence, completeness of the catalogue as a function of magnitude and time as well as clustering of events are significant properties to be taken into account for seismic hazard assessment. These two features and their effect on magnitude-frequency relationships are explored in the case of the earthquake catalog of Bangladesh. Based on a spatial analysis of the existing data mentioned above the distribution of seismic sources is derived (seismotectonic zones as well as single identified faults) which is another important input to seismic hazard assessment.

Session 2 / 12

Relative tectonic activity in the Colca catchment revealed by geomorphic indices, Central Andes

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Geomorphic indices are widely used to quantitatively appraise relative tectonic activity. Extensive, uncomplicated and nearly unlimited access to digital elevation models and GIS software essentially sustained the worldwide usage of those indices. Even though they can provide valuable information on active tectonics from landforms, the obtained data should be always corroborated in the field. Morphological diversity of the Colca basin in Central Andes has been evaluated as a possible effect of relative spatio-temporal variations in tectonic activity. This area is located in the forearc of the Nazca-South America subduction zone. High seismicity here results from megathrust earthquakes, numerous shallow earthquakes triggered by active crustal faults and volcanic seismicity linked to two active volcanoes (Sabancaya and Mismi) located in the Colca basin. In this study we used both approaches, i.e. selected geomorphic indices and geomorphic observations from the field. Fieldworks were dedicated mainly to 1) identify and measure landforms, 2) collect structural data, 3) verify bedrock lithology, and 4) confirm knickpoints location and their type, etc. Whereas for the analysis of geomorphic indices we used those that proved to be a signal of relative changes in forearc tectonic deformation, i.e. topographic swath profiles, river profile, stream-length gradient index (SL), minimum bulk erosion. For their calculation we used a 30-meter resolution digital elevation model from the Shuttle Radar Topography Mission (DEM SRTM), and digitized topographic maps. The longitudinal profile of the Colca River has a convex shape in the upper reaches and concave shape in the lower reaches with abrupt break (knick point) in the slope that do not correlate with changes in bedrock lithology. Anomaly high values of stream length gradient index and minimum bulk erosion occur in the intermediate part of the basin, suggesting higher erosion in this section of the basin. This agrees with and is supported by field observations, as it coincides with the deepest section of the river basin known as the Colca Canyon. Lack of correlation between observed pattern and variations in bedrock lithology suggest tectonic forcing. Local deviation in calculated indices, as well as observed in the field deformations of landforms are the most probably the results of the activity of regional crustal faults, particularly W-striking extensional ones, as indicates by structural data.

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Speleothem-based dating of the 1828 collapse in the Han-sur-Lesse cave: potential relation between cave collapses and seismic events.

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The two most recent collapses in the Han-sur-Lesse Cave (Belgian Ardenne), more precisely in the Dôme room, occurred on or shortly after 3rd December 1828 and between the 13th and 14th of March 1984. These collapses were directly observed by cave guides and occurred less than a year after the 23rd February 1828 (Mw =5.1 in Central Belgium) and 8th November 1983 (Mw=4.8 in Liège) earthquakes, which are the two earthquakes that generated the strongest ground motions in Han-sur-Lesse since 1800. Our study demonstrates the low probability that these occurrences are coincidental and therefore suggest a causal link between earthquakes and successive collapses in the Han-sur-Lesse cave. Lamina counting of a stalagmite growing on the 1828 debris dates the collapse at 1826 ±9 CE, demonstrating the possibility of dating previous collapses with a few years of uncertainty. Radiometric dating techniques such as U/Th opens the possibility to date older collapses and gain some insights in potential seismic periodicities where other indications are totally absent. Our study opens the debate whether collapse activation is an on-going process in the evolution of karstic networks related to the weakening of cave vaults. We suggest that earthquake activity could play a stronger role than previously thought in initiating cave collapses.

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Cacahuamilpa Cave, Mexico: a unique paleo-speleo-sismological and paleoclimate archive

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Paleospeleosismology is a discipline, which studies fallen stalagmites and stalactite as archives of past seismic events (Quinif, 1996; Gilli, 2005). Damaged or fallen speleothems (named seismothems) are often observed in caves, and first recognized at Han-sur-Lesse karst complex. There are several physical causes that can damage or break stalagmites: one is the reaction of the stalagmite – as an inverse pendulum – at the passage of a seismic wave (Szeidovitz et al., 2008). Here we present the Cacahuamilpa Cave karst complex, one of the largest in Mexico but which formation and evolution is still poorly documented. This karstic complex contains numerous fallen stalagmites, several one of giant dimensions, that could have been broken during large past seismic events. Cacahuamilpa Cave is located in the Guerrero state, at midway between Mexico City and Acapulco in one of the regions of Mexico with the higher seismicity caused by the subduction of the Cocos plate under the North American one. A few studies in the 60' and 70' suggested that the cave formed end of Pliocene as a suspended river channel into Cretaceous carbonates of the Morelos Fm. (Enjalbert, 1964; Bonet, 1971). Between 80kyrs and 50kyrs, one of the entrances of the karstic tunnel was sealed by lahar products of the nearby Nevado del Toluca stratovolcano (Capra et al., 2002). The karstic tunnel is disseminated of stalagmites with size variable from 1-2 meters long to 70 m high and 300 tons weight. Some of them are broken and oriented following precise patterns and orientations. Because of the total lack of geological ages, an ongoing study was initiated in 2013 to obtain a clear chronological framework of the construction of the speleothems and obtain reliable dates of the broken surfaces, using U/Th dating methods. First results published in Méjean et al. (2015) showed that three groups of stalagmites were broken between 80kyrs and Holocene (1000 years ago). Theoretical calculations suggested seismic events with magnitude of M 7-8 and epicentral distances of 50-100 km from the

cave. A recent survey in February 2018 was focused on two groups of stalagmites, one including the Calendario Azteca (The Aztec Calendar), a giant broken speleothem of 13 meters length and 3.5 m diameter. New U/Th dating showed that these stalagmites grow extremely fast and most of them in two short periods corresponding to the interstadials of the Marine Isotopic Stage 5, between 75kyrs and 90kyrs (5a, 5b) and 110 to 120kyrs (5d) (Liesecky and Raimo, 2005). These periods are characterized by high rate soft humidity and rainfall (Bar-Matthews et al.2000), which could have favored the precipitation of large amounts of carbonates creating the giant speleothems in the Cacahuamilpa cave. Speleothems of modest dimensions have been probably broken by seismic events but large ones are difficult to explain and alternatively hypotheses, such as sediment creeping when the cave was still opened on both sides and invaded regularly by volcanoclastic sediments, should be take into account.

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Session 2 / 15

Active faulting in the Upper Rhine Graben: geomorphological and geophysical evidence

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The Upper Rhine Graben (URG) is the central part of the Central European Cenozoic Rift System (ECRIS) and one of the tectonically active regions in Europe. The URG extends from the Jura thrust and fold belt in the South near Basle city (Switzerland) to the Rhenish Massif in the North near Frankfurt and is limited by sinistral strike-slip faults on either sides. Several studies suggested particularly the fault system at the eastern margin to be active, as the Basle earthquake 1356 AD was situated there. Ongoing earthquake activity testifies to active faulting, however, there are many faults and fault strands, many of them are regarded as normal faults, others as reactivated normal faults with a sinistral sense of movement. This is due to a major change in stress direction from SW-NE towards a SE-NW direction in Miocene times. The URG is a low-strain setting with long recurrence intervals of large earthquakes. Moreover, the fault morphological signal is perturbed by anthropogenic land-use, the climate of the area, which is located in the temperate zone, and the erosion and sedimentation of the Rhine River. The eastern margin faults lack any neotectonic and paleoseismological investigations, in contrast to the western border faults that have been examined during the last decades, while the area encompasses critical facilities in a vulnerable region such as, dense population, agriculture, mining, geothermal facilities. Our projects in the frame of an IRSN study and the DFG-SPP AlpArray aim to fill this gap of knowledge in large and infrequent earthquakes, through a paleoseismological investigation of eastern side faults. We used a multidisciplinary approach to improve the input data of seismotectonic models, which include faults and their activity potential in the calculation of seismic hazard assessment and are based on a weak data set at the moment. First results of different locations around Freiburg in the southern URG and around Karlsruhe are presented: the Rhine River fault system about 20 km SW of Freiburg, NE of Freiburg at the eastern border fault system about 10 km. At both sites we used a digital elevation model (DEM) derived from LiDAR-data (5x5m) and together with geophysical measurements performed with ground-penetrating radar (GPR) and electrical resistivity tomography in order to track and identify possible fault scarps. A detailed geomorphological study of the DEM was performed to identify and map superficial expressions of the neotectonic activity of the faults and deformed and offset alluvial terraces and fans. We apply ERT and GPR for imaging the geophysical contrasts at depth, such as faults and stratigraphy in detail. Nevertheless, for the unambiguous verification of these

structures and the determination of key fault parameters, such as magnitude, age of last events, slip rate and return periods, additional paleoseismological trenches are needed, which will be the next step of the project.

Poster Session 1 / 16

Features caused by ground ice growth and decay in Late Pleistocene fluvial deposits

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Last Glacial fluvial sequences in the Paris Basin show laminated lacustrine deposits OSL and radiocarbon dated to between 24.6 and 16.6 ka in one site and overlying alluvial sandy gravel. A thermokarst origin of the lakes is supported by abundant traces of ground ice, particularly ice wedge pseudomorphs beneath the lacustrine layers and synsedimentary deformation caused by thaw settlement. The features include brittle deformation (normal and reverse faults) resulting from ground subsidence owing to ice melting and ductile deformations caused by slumping of the sediments heaved by the growth of ice-cored mounds. These correspond to lithalsas (or lithalsa plateaus) and/or to open system pingos. At least two generations of thermokarst are recorded and may reflect the millennial climate variability typical of the Last Glacial. The structures studied in quarries are associated with an undulating topography visible in 5-m DEMs and a spotted pattern in aerial photographs. The search for similar patterns in the Paris Basin indicates that many other potential thermokarst sites exist in the Last Glacial terrace (Fy) of rivers located north of 48N when they cross the lower Cretaceous sands and marls. In some sites, the presence of organic-poor, fine-grained deposits presumably of lacustrine origin was confirmed by borehole data. The site distribution coincides broadly with that already known for ice wedge pseudomorphs. This study provides new evidence of permafrost-induced ground deformations in France and strongly suggests that thermokarst played a significant and probably largely underestimated role in the genesis of Late Pleistocene landscapes.

Session 1 / 17

On the consequences of the Fennoscandian earthquake of 23 October 1904

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There is a wide consensus on the magnitude, Ms5.4, of the Fennoscandian earthquake on 23 October 1904, which makes it the largest onshore/nearshore event in the region during the 1900s. In much of the available literature it is known as the Oslofjord earthquake. An earthquake of this magnitude is rare in the Fennoscandian Shield, so it is meaningful to extract all possible information about it.

At the time, seismic stations existed, although their spacing was not dense. Bungum et al. (2009) located the earthquake epicentre instrumentally in the vicinity of the Koster Islands by the border between Norway and Sweden.

The earthquake was widely felt in the southern halves of Norway and Sweden and northern Denmark, and also on the other side of the Baltic Sea in Finland, Estonia, Latvia and Lithuania as

well as along a coastal strip of northern Poland and Germany. Several contemporary publications described the earthquake effects at different locations; even a few specific macroseismic surveys were initiated. Much macroseismic data are thus available for the earthquake of 23 October 1904. However, the earthquake occurred on Sunday during mass, and in very many places macroseismic descriptions originated only from churches.

This ongoing investigation focuses on the damages caused by the earthquake. They are minor on the global scale, but interesting regionally when well documented. The present notion is that vulnerable structures could be affected at relatively long epicentral distances. Indirect fire hazard was reported from very long distances, which might have followed from cracked masonry parts of buildings.

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Session 4 / 18

Dating two very young stalagmites by ^{210}Pb excess method: examples from the Han-sur-Lesse karst complex, Belgium

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Stalagmites can provide very high-resolution (seasonal to annual) continental archives for paleoenvironmental reconstructions (Bar-Matthews et al, 1991, Bar-Matthews et al, 1997) due to their precise chronology and their ability to register climatic and environmental changes through proxy-tools such as stable isotopes $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ (McDermott, 2004) and trace elements (Fairchild et al, 2000, 2001). Fallen or broken speleothems can be also used as record of past earthquakes (seismotheims) (Quinif, 1996). However, to create precise paleo-seismic catalogues, as well as paleoclimatic detailed records at the century timescale, new dating methods need to be developed. The ability of precisely dating speleothems by U-series decay chain (U/Th disequilibrium) has played an important role for the choice of speleothems as reliable proxies for paleo-environmental reconstructions for the last 500kyrs (Upper Pleistocene timescale). However, studies of younger speleothems are still poorly documented because the difficulties in using U/Th dating method at century timescale. Speleothems often contain low U-contents (ppb levels) and traces of detrital contaminants, which require complicated age corrections. Such corrections result in relatively high uncertainties on the final age calculation. A very limited number of studies were done using ^{210}Pb excess for dating young speleothems (Baskaran and Iliffe, 1993). Here we present the results of ^{210}Pb on two actively growing laminated stalagmites from Han-sur-Lesse karst complex, Belgium. The main objective of this work is to demonstrate the ability to use ^{210}Pb as a dating tool for young stalagmites. The variations of the activities of ^{210}Pb along of growing axis show near ideal exponential fit indicate the possibility of using this method as a dating tool for such stalagmites and several age models were established. In order to validate the ^{210}Pb ages, results were compared with annual counting laminae ages. The results show a well agreement between the ages derived from ^{210}Pb and those from laminae counting for the last 100 yrs. Next step will be to validate the reconstruction of climatic signal obtained through stable isotopes ($\delta^{13}\text{C}$ and $\delta^{18}\text{O}$) and compare the results with climate instrumental data available for the region.

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Poster Session 1 / 19

Earthquake catalogue for the XIXth century from the Lower Rhine Embayment to the North Sea: summary and results.

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Earthquake catalogue for the XIXth century from the Lower Rhine Embayment to the North Sea: summary and results.

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The Royal Observatory of Belgium, Cologne University and the Royal Netherlands Meteorological Institute (KNMI) are conducting since 5 years a specific research to establish a reliable earthquake catalogue for the XIXth century based on already known original documents but also on new ones systematically searched for and retrieved from various archives. The transfrontier and multilingual study area reaches from the Lower Rhine Embayment to the North Sea. In parallel a thesis from the University of Liège on the earthquakes felt in Belgium since 1795 until 1911 are studying 28 events on the seismological and historical point of view. Among them the most important events of the century: 1828-02-23; 1828-12-03; 1878-08-26 and 1881-11-18.

One of the most important discovery was done at the occasion of the 3rd December 1828 earthquake: the first official surveys conducted after earthquakes in our regions. They was sent out by the Prussian government to the commissioners and burgomasters of various districts. We collected a significant amount of new material demonstrating that this kind of survey was routinely utilized on a large scale in additional instances of felt earthquakes by the Prussian authorities and that it continued up to the end of the XIXth century. This discovery prove the importance of new historical research on earthquakes to confirm or not some famous works written by previous scientists and revise intensities and epicentre of some events.

Session 2.2 / 20

Surface rupture associated with a moderate intraplate earthquake: the Mw 6.2 Parina event (December 1st, 2016) in the Peruvian Altiplano

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Fault displacement and Seismic hazard analyses employ empirical relationships to predict potential earthquake magnitude ("scaling relationships"; e. g., Wells and Coppersmith, 1994), surface slip), probability functions of surface rupture and surface slip amount (e. g., "conditional probability of rupture" and "probability of exceedance", respectively; see Youngs et al; 2003). Those

relationships share the common issue that they rely on a limited number of moderate-to-large magnitude (≥ 6.5) and pre-2000 cases. Earthquakes from western US and Japan are largely represented, and intraplate cases are few. Here, we report surface faulting evidence that occurred during a moderate earthquake that occurred in the Altiplano of Southern Peru. We present field and high-resolution data that improve the geodynamic knowledge of the region and provide clues to upgrade seismic hazard tools. The 2016 Mw 6.2 Parina normal-faulting earthquake occurred within the high Andes of southern Peru in a region with sparse recent seismicity and no observable geodetic horizontal strain. Field observations and high-resolution DEMs of the surface ruptures allow investigating the relationship between slip on the Parina Fault, local geomorphology and the regional tectonics. We mapped one major NW-SE-trending and 6-km-long segment, with up to ~27 cm vertical slip (downthrown to the SW) and ~25 cm tensional opening. Surface slip is not distributed off the main fault, with the exception of a parallel strand 200-m off the major one at its northern tip. One striking point is a minor NW-SE-trending and 1.5-km-long ruptured segment with smaller slip values (up to 8 cm) distant by 5 km to the north, along the same fault zone. The two mapped rupture traces directly coincides with the up-dip projection of the co-seismic fault plane inferred from InSAR measurements, and they therefore may represent two distinct surface sections of the primary earthquake fault, separated by a surface gap. This gap occurs where surface geology is constituted of loose sediments. The ruptures coincide with 10-20 m high scarps cutting through fluvio-glacial deposits that are downthrown to the SW, and they form the southeastward extension of the larger Lagunillas-Mañazo fault system that trends NW-SE across the Peruvian Altiplano. A preliminary estimation leads to infer a repeated normal-sense slip on the Parina Fault since the last major glaciation (~10-30 ka), implying a vertical slip rate ~1 mm/y. Besides its regional interest in terms of active tectonics and geodynamics (Wimpenny et al., 2018), the Parina surface rupture 1) constitutes a new case to enrich the pending SURE database with new accurate data, especially for intraplate events, 2) surface geology is a key parameter influencing the surface slip, 3) illustrates once again that moderate earthquakes can rupture the surface in a complex pattern, 3) shows that high-resolution techniques allows improving the characterization of surface ruptures (rupture length and max/mean displacement) and 4) potentially questions the fault parameters that were inferred in the past when such approaches were not available. Those are arguments that support the idea of the need for a deep revision of empirical relationships, based on catalogues of modern earthquakes.

Poster Session 1 / 21

First assessment of recent tectonics and paleoearthquakes along the Irtysh fault (eastern Kazakhstan)

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The Asian plate interiors are known to have host strong earthquakes with magnitudes up to $M \approx 8$ in recent history, especially around the border area between Mongolia, Kazakhstan, China and Russia (e.g., M7.3 Chuya earthquake, 2003). Their recurrence times seem to be long, because of the relative low slip rates (less than 1 mm/y) of the faults which caused them. In this study, we focus on a large inherited fault zone (namely the Irtysh Fault Zone) with no historical earthquakes larger than M6, to test whether this structure could have generated surface-rupturing events during the last thousands of years, like some other historically silent similar faults of cratonic southern Kazakhstan did in pre-historic times. To do so, we use tectonic-morphological analyses of satellite images and trenching across several fault portions to detect potential paleoearthquakes. The Irtysh Fault Zone (IFZ) is a 250+ km long basement set of faults that marks a major tectonic block boundary between different units with Paleozoic magmatic rocks and thick deposits of Late

Paleozoic age. The formation of the IFZ dates back into the Late Paleozoic times during collision between Siberia-Kazakh cratons and it was repeatedly reactivated in later times (e.g., Oligo-Miocene). The Quaternary activity of the Irtysh Fault Zone has never been addressed in modern studies and, in this study, we document for the first time that the IFZ is an active fault and is a potential source of large earthquakes in easternmost Kazakhstan. Our analyses actually revealed, at different spots along the IFZ, the occurrence of a set of lineaments offsetting lithologies or deflecting streams and other landscape features. Trenching sites across those lineaments eventually confirmed that they were active fault strands and in some trenches, 14C-dated Holocene-Late Pleistocene deposits are clearly faulted. Those recent deposits include organic soils, loess layers and colluvium directly overlying the Paleozoic rocks. Our findings lead to the conclusions that the IFZ is clearly active along several strands of its trace in bedrock. During the Holocene, it hosted earthquakes with surface rupture individual displacements of up to 1.5 meters, suggesting events with a magnitude around $M \approx 7$. However, our investigations do not allow to confident estimation of slip rates: we propose for one fault section parallel to the main fault a preliminary estimation of ~ 0.22 mm/y vertical displacement rate, based on a single trench. Based on regional morphoclimatic arguments and landscape features offsets, we also propose a first assessment of the lateral slip rate along the major fault between 0.3 and 0.5 mm/y. Additional investigations should be undertaken to refine surface fault mapping, the paleoearthquake calendar, the slip rate, and potential along-strike evolution, in order to constrain future seismic hazard analyses with fault models in this region of Eastern Kazakhstan.

Session 1 / 22

Seismicity in Switzerland in the early instrumental period Re-assessment of the period 1911-1963 from a heterogeneous dataset

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Seismicity in Switzerland in the early instrumental period Re-assessment of the period 1911-1963 from a heterogeneous dataset

After the compilation of the Swiss Earthquake Catalogue ECOS-091 the next logical step in the process of improving historical earthquake information for Switzerland is the historical-critical revision of the seismicity of the period from 1878 to 1974. This is presently carried out in an interdisciplinary project funded by the Swiss National Science Foundation (2015–2019). The examined time span covers the pre-instrumental [1879–1912] and early-instrumental period [1913–1963] of systematic scientific earthquake observation in Switzerland. The transitory period of 1964–1974, characterized by technical reconfigurations and a particular lack of documentation, has been addressed in an earlier project phase. Due to the generally increased production of scientific data in this time range, we have the possibility for an in-depth analysis of a larger number of events with a sufficiently rich data base. To complete the investigations performed in the framework of ECOS-09 we can extend our focus to the intermediate-size events of epicentral intensities in the range IV–VI (in the European Macroseismic Scale EMS-98). Whereas the documentation of the pre-instrumental period of systematic scientific earthquake observation by the Swiss Earthquake Commission SEC (1879/80–1912) can mainly rely on detailed macroseismic information³, the source situation gets more complex with the advent of instrumental observation and the establishment of the Swiss Seismological Service (SED) in 1912/14. The assessment of this later period involves a multi-tiered analysis of a broad variety of sources containing both qualitative and quantitative data: descriptive reports and parameterized macroseismic information on the one side and historical seismograms and instrumental parameters on the other. This heterogeneous dataset is systematically gathered, archived and made accessible in this project. The large stock of historical seismograms a. o. recorded by a unique network of 3-component-Seismographs with pendulum masses of up to 21 tons and amplification factors of roughly 2000x is made accessible in a common sub-project with the ETH university archives. All events that have reportedly been felt within Switzerland are scanned in high resolution. The early instrumental period provides us with a rich and diverse set of data that can be used to improve our understanding of seismicity and source-depth distributions as an important element

for future seismic hazard and risk assessments. Both in the case of the macroseismic as of the instrumental data we have extraordinarily long relatively homogeneous data sets at our disposal, as the relevant instrument settings and the intensity scales in use remained unchanged during decades. However, both the macroseismic as the instrumental data show important gaps in tradition, due to neglective record keeping in the past and other factors. Used complementary, the different datasets may thus allow us to fill transmission gaps respectively. The datasets will allow cross-comparisons in further studies and can be used for calibration procedures. The examination of the historical practice of data production and the comparison of this historical macroseismic dataset with macroseismic re-assessment in the modern EMS-98 scale can provide valuable insights for an empirical scale conversion. This may enable us to use the collected original intensities assessed in Rossi-Forel (for most of which primary data are lost) in the reconstruction of macroseismic fields.

Session 2.2 / 23

30 October 2016-type earthquakes rupturing the Mt. Vettore-mt. Bove fault system (Central Italy) during the Holocene

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A campaign of paleoseismological investigations was performed on the nearly 22 km-long coseismic surface rupture of the 30 October 2016 Mw 6.5 normal-faulting earthquake in Central Apennines. The main goal was the definition of the maximum magnitude, the average rate of displacement and the frequency of seismic events on the Mt. Vettore-Mt. Bove fault system (VBFS hereinafter). We show the results from the analysis of three trenches at different sites, one dug across a synthetic rupture strand and two across antithetic strands, as well as the integration of other paleoseismic data collected along the VBFS at different time. A major finding of our field campaign is the recognition of slip events associated with individual earthquakes affecting deposits of Holocene age based on radiocarbon dating. The paleoevents are very similar in geometry and size of deformation (up to 0.5 m of throw) to the 30 October 2016 event and re-ruptured the same fault portions within thousands time-windows. Then, paleoseismicity confirms that the VBFS growth develops during large seismic events where surface slip tends to concentrate on the same splays involved in the 2016 October earthquake rupture process, including minor antithetic faults. Moreover, the 30 October rupture traces overprinted and magnified those produced by two previous spatially and temporally clustered mainshocks of lower magnitudes, like the 24 August Mw6.0 to the south and partially the 26 October Mw5.9 to the north (Villani et al. 2018 Tectonics and references therein), involving previously activated faults as well as additional strands of the VBFS. This proves that surface ruptures can re-occur on the same portion of a fault system even within a few days/months, a scenario that has been seldom documented so far. From a paleoseismic perspective, this extreme case of very short lapses of time between surface faulting events and the observed complexity of rupture traces highlight how critical can be the reconstruction of discrete slip events in trenches stratigraphy.

Poster Session 1 / 24

3D characterization of the geometry impact on the seismic response of complex reinforced concrete buildings using the transfer function method

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Archaeoseismology investigates the characteristics of past earthquakes on the basis of the observed and recorded damages on historical buildings or archaeological remains. To better achieve this scope, an important step might be the setup of the numerical modelling of past structures. Indeed, the seismic response of a building is intrinsically related to its geometry and mechanical properties, soil structure interaction and the waves propagation through the medium. Faced to the complexity of the detailed simulation of all these processes, we are implementing a simplified approach based on the analysis of structural typologies. One of the criteria introduced to discriminate buildings behaviour is their geometry.

For this reason, as a first step before our archaeoseismological works, we hereafter focus on the impact of the geometry of building. To simplify the analysis we focus on reinforced-concrete buildings, whose mechanical behavior is well known.

It is a common belief that the more a building presents simple shapes, the more it is resistant to earthquake shaking. However, irregularly shaped buildings are nowadays widely present in both Urban Civil Engineering and industrial facilities.

With the aim to test the shape-dependent seismic response of the buildings, we designed 15 different buildings having different shapes and foundations. Thus, we performed a large amount of dynamic seismic analysis using more than 300 recorded accelerograms.

The structure response is described in terms of Engineering Demand Parameters. We particularly focused on shear strength induced by the structure rotation, normalized by the normal strength. We show that seismic response is mainly controlled by the building mass, the used typology, and soil structure interaction rather than the floor geometry.

Such conclusions will help us to model historical buildings and interpret the observed damages in order to quantify past motions.

Session 4 / 25

Estimating the upper limit of prehistoric peak ground acceleration using an in-situ, intact and vulnerable stalagmite from Plavecká priepast cave (Detrekői-zsomboly), Little Carpathians, Slovakia

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Earthquakes hit urban centers in Europe infrequently, but occasionally with disastrous effects. Obtaining an unbiased view of seismic hazard (and risk) is therefore very important.

In principle, the best way to test Probabilistic Seismic Hazard Assessments (PSHA) is to compare them with observations that are entirely independent of the procedure used to produce PSHA models. Arguably, the most valuable information in this context should be information on long-term hazard, namely maximum intensities (or magnitudes) occurring over time intervals that are at least as long as a seismic cycle. The new observations can provide information of maximum intensity (or magnitude) for long time scale as an input data for PSHA studies as well. Long-term information can be gained from intact stalagmites in natural caves. These formations survived all earthquakes that have occurred over thousands of years, depending on the age of the stalagmite. Their “survival” requires that the horizontal ground acceleration (HGA) has never exceeded a certain critical value within that time period.

Here we present such a stalagmite-based case study from the Little Carpathians of Slovakia. A specially-shaped, intact and vulnerable stalagmite in Plavecká priepast cave was examined in 2013. This stalagmite is suitable for estimating the upper limit of horizontal peak ground acceleration generated by prehistoric earthquakes.

The critical HGA values as a function of time going back into the past determined from the stalagmite that we investigated are presented. E.g. at the time of Jókó event (1906) the critical HGA value cannot have been higher than 1 m/s^2 , and 1.3 m/s^2 at the time of the assumed Carnuntum event ($\sim 340 \text{ A.D.}$), and 3 thousand years ago it must have been lower than 1.7 m/s^2 . We claimed that the effect of Jókó earthquake (1906) on the location of the Plavecká priepast cave is consistent with the critical HGA value provided by the stalagmite we investigated. The approach used in this study yields significant new constraints on the seismic hazard, as tectonic structures close to Plavecká priepast cave did not generate strong earthquakes in the last few thousand years. The results of this study are highly relevant given that the two capitals, Vienna and Bratislava are located within 40 and 70 km of the cave, respectively.

Session 2.2 / 26

Surprisingly high post-glacial fault slip rates in a slow deforming area: the case of the Culoz fault system (French Jura Mountains)

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The north-western Alps foreland (Jura Mountains) is considered as still experiencing distal effects of the Alpine collision, resulting in a moderate but significant seismicity. This study focuses on the Culoz strike slip fault, developing from the Jura Mountains to the West, to the Chautagne swamp and through Lake Le Bourget to the East. Because erosion and anthropogenic activities erased most of the potential geological markers of quaternary deformations on land, we used high resolution seismic imaging to detect and characterize active faulting in the Quaternary sediments of the Bourget post-glacial Lake. The well-stratified character of the lake infill is locally disturbed by tectonic deformations associated with the activity of the left lateral Culoz fault as well as gravity reworking. Taking into account the age of the sediments (based on core samples), a quantification of the observed deformations together with the analysis of a well preserved outcrop on land, attest for fault slip-rates ranging from 0.055 to 3.11 mm/yr, the latter being surprisingly high in comparison with what we know elsewhere in France. A comparison with core-drills obtained in the neighboring lakes (Beck, 2009) allows us to envisage a non-stable seismic activity along the fault through time, and to propose a dominant control of the deglaciation on the observed fault slip-rates.

Poster Session 1 / 27

Did seismic shocks damage speleothems in Central Carpathian caves?

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Seismic activity has been instrumentally recorded in the Central Western Carpathians, both in Slovakia and Poland. Many earthquakes were registered in ancient written sources, such as chronicles. Compilation of instrumental data and historical sources shows that epicenters of earthquakes are clustered in zones, which is an expression of the regional faults pattern. Several seismically active zones had been distinguished in the Central Western Carpathians and this mountain chain was regarded as the 'shallow crustal active region'. Seismic events in the Carpathians result from neotectonic processes that are associated with the collision of the ALCAPA microplate with the European plate. The history of the seismicity in the Central Western Carpathians has so far been based solely on instrumental record and historical data. The study of speleothems may lead to unraveling the Middle Pleistocene to Holocene seismic history of the Central Western Carpathians. This area abounds with caves where naturally damaged speleothems occur. Although some data suggest ice and frost action as the reason for speleothem destruction, the involvement of seismic activity is one of the possible causes of such damage.

The present study concentrates on naturally damaged speleothems, especially: (i) fractured and broken speleothems, (ii) tilted stalagmites, (iii) displaced pairs of stalactite-stalagmite, (iv) collapsed parts of ceiling including speleothem overgrowths (flowstones and stalactites), (v) fallen stalactites (including fragile soda-straw ones), (vi) layers with angular debris and broken speleothems cemented within flowstones.

Preliminary results provide some examples which support the idea of involvement of seismic activity in destruction of speleothems. Study of speleothems in the Tatra Mts. may serve as one meaningful example. Speleothem destruction and their subsequent regrowth took place there synchronously ca. 95 ka. This period is regarded as relatively warm, thus deep frost action as a causing mechanism can be ruled out. Another example is the 32 m tall stalagmite in Krásnohorská Cave (the Slovak Karts area), one of the highest stalagmites known worldwide. The stalagmite is severed; its former summit is collapsed and wedged in the cave passage near its bottom. A huge earthquake seems to be most probable cause of this damage.

Precise dating of damaged speleothems in the Central Western Carpathians caves, preceded by a careful selection of samples for dating, should have a great potential to expand the chronology of seismic activity in this area back to the geological history.

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Seismically involved soft sediment deformation in clastic cave deposits of the Kalacka Cave (Tatra Mts, southern Poland)

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Soft sediment deformation were recognized within poorly-lithified Upper Pleistocene siliciclastic deposits, filling one of the cave passage in Kalacka Cave in Tatra Mts (southern Poland). Structural analysis revealed that soft sediment deformations are represented by micro faults and micro folds (disharmonic folds, fault-bend folds, upright anticlines), water escape structures, and load structures. Laboratory tests based on acoustic measurements (S-wave velocities and densities of siliciclastic deposits and host rock) and calculations (amplification coefficient and resonance frequency) demonstrated that soft sediment deformation developed in result of sediment liquefaction. Obtained values of vulnerability index ($K_g > 5$) and resonance frequency (ca. 17.5 Hz) suggest sediment liquefaction could be involved by ground shaking, which in case of study area resulting from rock mass relaxation.

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Challenges of the new ESC Working Group Macroseismology - Integrating corrective parameters to merge multiple-sourced online macroseismic data

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The practice of macroseismic investigation through internet inquiries is well established among numerous seismological institutions around the world, thanks to wide citizen participation. Although internet macroseismic data analysis has reached high levels in Europe, intensity methods adopted by each one of the national research institutes are still quite different and usually tailored to the needs of country-specific urban-structural settings and seismicity. This European fragmentation of data collection and analysis requires an urgent effort to harmonise macroseismic methods and to simplify data exchange.

At the 36th General Assembly of the European Seismological Commission 2018 Meeting in Malta, a new ESC Working Group in Macroseismology (2018-2022) was composed aiming to improve macroseismic data exchange, to review national macroseismic practice and to encourage/facilitate cooperation among research groups for cross-border felt earthquakes and multiple source macroseismic data acquisition. Working Group products will be comprehensive European macroseismic intensity catalogue creation, framed within EPOS, and a definition of calibration parameters for database compatibility applied on multi-country and/or multi-institution data events. Instead of proposing a common, standardized procedure/questionnaire to produce an homogeneous dataset, we will develop an alternative approach consisting of respecting the differences among various strategies used to collect and analyse data, and applying a statistical evaluation of differences for the definition and implementation of corrective parameters.

In this study this procedure is demonstrated on macroseismic data of several Italian earthquakes: i.e. the 2017 Mw 5.1 Amatrice, 2016 Mw 6.5 Norcia, 2016 Mw 6.0 Norcia, 2016 Mw 5.9 Visso, 2013 Mw 5.1 Fivizzano earthquakes, for which intensity data was provided by different institutions (INGV-HIST, EMSC, USGS-DYFI). Statistical methods were used to evaluate, in a quantitative way, the degree of agreement and differences between these three datasets, and the possibility to retrospectively merge data, in order to obtain more uniform and stable intensity data. Preliminary results show that merging these three datasets, without applying any correction, results in a near-field intensity underestimation (lack of proper damage estimation in all databases) and far-field intensity overestimation (lack of non-felt reports in USGS and EMSC databases).

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A New Paradigm for Large Earthquakes in Stable Continental Plate Interiors

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Large earthquakes within stable continental regions (SCR) show that significant amounts of elastic strain can be released on geological structures far from plate boundary faults, where the vast majority of the Earth's seismic activity takes place. SCR earthquakes show spatial and temporal patterns that differ from those at plate boundaries and occur in regions where tectonic loading rates are negligible. However, in the absence of a more appropriate model, they are traditionally viewed as analogous to their plate boundary counterparts, occurring when the accrual of tectonic stress localized at long-lived active faults reaches failure threshold. On the basis of a series of observational arguments, we will make the case that SCR earthquakes are better explained by transient perturbations of local stress or fault strength that release elastic

energy from a pre-stressed lithosphere. As a result, SCR earthquakes can occur in regions with no previous seismicity and no surface evidence for strain accumulation. They need not repeat, since the tectonic loading rate is close to zero. Therefore, concepts of recurrence time or fault slip rate do not apply. As a consequence, seismic hazard in SCRs is likely more spatially distributed than indicated by paleoearthquakes, current seismicity, or geodetic strain rates.

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Analysis of post-earthquake reconstruction in Pompeii (RECAP Program)

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Due to its particular geological context, the town of Pompeii and its surroundings are an exceptional ‘laboratory’, subject to a double volcanic and seismic risk. It stands out as it was the victim of two earthquakes before the eruption of Vesuvius in 79 AD. The first, in 63 AD is well known because it is recorded in the texts of Seneca and Tacitus, while the second, which happened around the year 70 AD, is only identified in the archaeological records from the site. The project RECAP aims to reproduce the conditions of reconstruction and the technical choices made according to the perceived risk in this symbolic Roman town. It is based on a pluridisciplinary approach (archaeology, 3D modelling, and structural engineering). We will present more specifically the archaeological methods and databases, which allowed determining the typology of building techniques and post-earthquake repairs.

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Elements of a Comprehensive Archaeoseismological Study

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Earthquakes cause ground motions and ground motions can cause damage to engineered structures. Engineering seismology’s main goal is to design structures that withstand such ground motions. Models for simulating ground motions, given that the seismic source and the travel path parameters can be assumed or are known, can be constructed which can help quantify damage scenarios. By applying a variety of models, the dynamic behavior of engineered structures can be calculated. In archaeoseismology, the timeline of operation is reversed. It is a discipline that includes time travel; i.e., to reconstruct the site when the damage occurred as opposed to merely modeling a contemporary structure and its associated geology. In addition to the geology, the only available data is the evidence of structural damage revealed by archaeological techniques in ongoing or completed excavations; in the latter case, documentation may be limited. Therefore, the task becomes one of starting with the damage, and then travel backwards in time, make models, evaluate possible non-seismic causes, estimate ground motion characteristics, and eventually conclude on the existence and character of the assumed earthquake source.

The tools available to the quantitative archaeoseismologist include Finite and Discrete Element techniques to virtually test structures and the considerable range of methods available to calculate synthetic site-specific seismograms. On-site data acquisition is often necessary to quantify parameters required for the models, and these include estimates for anthropogenic structures and the subsurface. The complexity of the problem introduces large uncertainties in the results; however, by continuously striving to quantify, these methods can also provide a reasonable estimation of uncertainty, more so than ‘common knowledge’ interpretations of archaeologically documented damage. We use field cases from Greece, Turkey, Israel and Italy to illustrate the quantitative concept.

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Present-day knowledge and questions about seismic versus aseismic activity of the Anatolian Faults in Turkey integrating historical earthquakes, paleoseismic studies and creep evidenced by Insar studies.

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The North and East Anatolian Faults in Turkey are two large conjugate strike-slip faults characterized by earthquakes of magnitude equal or larger than 7 and creep, which makes it difficult to evaluate their long-term seismic activity and the related seismic hazard. The North Anatolian Fault (NAF) ruptured from east to west in a westward propagating sequence of $M > 7$ earthquakes since 1939 and is characterized by partial creep in its central segment since its rupture. Its activity was recorded in historical document studies over more than 1000 years, and in a number of paleoseismological studies. Their compilation (Fraser et al., 2010) evidences different pattern of fault ruptures along strike. The western transtensional section displays short recurrence intervals and switching between furcated fault strands. The central translational section shows a normal earthquake distribution and ruptures in unison or in close succession. The role of creep has yet to be evaluated, but this segment displays a very weak relation between accumulated strain and displacement. The eastern transpressional segment more closely interacting with the East Anatolian Fault (EAF) and the indenting Arabian plate shows a bimodal distribution. The EAF was active during the 19th century according to historical documents and was mostly quiet during the 20th century. An Insar study (Cavalié and Jónsson, 2014) suggests full creep along its central part. Its historical record of earthquake is slightly less extensive than along the NAF, but still covers ~1000 years. Yet the EAF has been poorly studied. In particular, its paleoseismological record is very scarce, except near Hazar Lake located along the central creeping segments of the EAF. Paleoseismological trenches east of the Lake evidence only one event in the last 5500 years on the master fault and recurring ruptures along a close splay fault (Cetin et al., 2003). Several evidences of strong seismic shaking (i.e. ball and pillows, paleoliquefactions and fracturing linked to lateral spreading) were documented in the alluvial sediments of the large delta at the southwestern end of the Hazar Lake and their timing could correspond to destructive historical events (Hubert-Ferrari et al, 2017). Finally seismoturbidites in the deep lacustrine sediments attest for repeated clustered paleoshaking. The integration of historical and paleoseismological studies with Insar results rises questions about the long-term creep along the EAF and the role of splay faults. A long record of paleoruptures evidences in paleoseismological trenches along the principal displacement zone is needed to understand the long-term behavior of this fault. Such a study could have an impact on our understanding of seismic versus aseismic motion on large continental strike-slip faults.

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Location and kinematics of the Southern Issyk-Kul Fault in eastern part of the Issyk-Kul Depression, the Tien Shan

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The Issyk-Kul intermountain depression has a border with the Terskey Ala-Too Range in the south. Formation of these structures of the Tien Shan goes in conditions of the continental compression caused by a collision of Eurasian and India lithosphere plates. In the south a contact of the depression and mountains goes along Pre-Terskey Border Fault. Structure of this fault is a complicated system consists of main plane and second-order faults responsible for foothills formation. It is known that mountain ranges thrust onto adjoining depressions and their faults are tilted under the ranges. In the south of the Issyk-Kul Depression the faults behave differently: their planes tilted northwards forming reverse faults or underthrusts. Last decade there is proposed an idea that Terskey Ala-Too Range is so called “flower structure”. From “flower stem” in a depth the second-order faults are splayed upwards. The last faults form foothills. For the southern part of the Issyk-Kul Lake region Reed Burgette [2008] has elaborated a model of the fault tilted southward and becoming more gentle northward. Pre-Terskey Border Fault goes along a contact zone of Cenozoic deposits of the Issyk-Kul Depression with Paleozoic rocks of the Terskey Range. The Dzhety-Oguz horst-anticline (located southern) is torn from the south by a young fault of reverse or underthrust’s type. The fault torn its steep and short southern limb. At the same time in northern - long and gentle limb of the Dzhety-Oguz anticline one can observe firstly the conform overlapping of the pre-orogenic penepain by Jurassic deposits, then secondly (moving northward) the conformable overlapping of Jurassic by deposits of Paleogene, Neogene and Quaternary periods. The age of Cenozoic deposits becoming younger northward, an angle of their tilt is becoming more gentle. To the south from the Dzhety-Oguz foothill fault which is tilted northward there is the plane of Pre-Terskey border fault tilted southward. Between these faults there is a small intramontane depression filled by Quaternary deposits. The only one significant fault is located north of Dzhety-Oguz fault, it is a fault limited from the north the Orgochor intradepression uplift. To the last one as well as to Birbash, Sukhoy Khrebet, Tepke, Tosma and other intradepression uplifts there is located the fault tilted southward and becoming more gentle northward. All these structures have clear northern asymmetry: their northern limbs are short and steep, torn by the fault. Sothern limbs - long, they gently subside under extensive alluvial plane of south-eastern Issyk-Kul Lake region. These fault-generated anticline uplifts substitute each other in echelon-like manner eastward and are morphological manifestation of most northern appearance of Pre-Terskey fault zone, which we called Southern Issyk-Kul Fault. Thus besides vertical component formed mentioned intradepression uplifts there is also horizontal sinistral component of recent strike-slip fault’s tectonic movements. Our study was conducted at financial support of the International Science and Technology Center (grant No. G-2153) and State Program of Scientific Research of Schmidt Institute of Physics of the Earth RAS.

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The paleoseismological dataset of Switzerland

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Earthquake hazard models are based on data from the instrumental and historical records. However, in regions where deformation rates are low, the recurrence rate of large earthquakes may exceed the timescale covered by these datasets. Thus, it is crucial to collect paleoseismological information over longer timescales. In Switzerland, a considerable number of studies has been performed gathering information on possible prehistorical earthquakes. This study represents a compilation of existing paleoseismological data from the different research fields: Sedimentology – Archeology – Speleology – Geomorphology and Historical records. The raw data are homogenized into one database and will complement the existing ECOS database of historical earthquakes. This new database covers the past 20,000 years and reveals 15 periods with an increased number of paleoseismological evidences. The systematic collection and interpretation of paleoseismological observations proved to be a valuable approach for detecting possible large pre-historical earthquakes and helps set priorities for future research. These datasets might also represent valuable contributions for the next generation of earthquake hazard maps. In future steps, a comparison of the earthquake hazard model of Switzerland and the paleoseismological dataset for a “sanity” check of the hazard model is planned.

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Causes and hazard of lake tsunamis: a multidisciplinary approach from Swiss LakesKREMER, Katrina¹¹ *Swiss Seismological Service, ETH Zürich, Sonneggstrasse 5, 8092 Zurich***Corresponding Author(s):** thomas.lecocq@seismology.be

Marine tsunamis have been increasingly discussed in the context of ocean-wide natural hazards since the 2004 Sumatra and the 2011 Tohoku earthquake tsunamis. While ocean tsunamis are usually caused by earthquake-related plate displacements, tsunamis in lakes can have a seismic or aseismic cause. The wave-causing mechanisms are usually related to mass-movement processes that displace large amounts of water causing devastating waves. Historical evidences in Switzerland has shown that tsunamis occurred in many lakes (e.g. 563 AD in Lake Geneva, 1601 and 1687 AD in Lake Lucerne etc.) causing large damage and also casualties. The causes of these tsunamis were diverse and varying between the different lake basins and events. An interdisciplinary Sinergia project, funded by the Swiss National Science Foundation, uses the outstanding field laboratory of Switzerland's lakes to understand better lake tsunamis by investigating their trigger mechanisms, wave propagation, inundation, sedimentation processes and their related hazard. In this contribution, we will present the project and highlight the main objectives.

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Macroseismic field mission in Mayotte after the seismic sequence in May and June 2018**Author(s):** SIRA, Christophe¹**Co-author(s):** SCHLUPP, Antoine ² ; BONTEMPS, Martial ³ ; REGIS, Edouard ³¹ *EOST (Ecole et Observatoire des sciences de la Terre - Strasbourg)/UMS830-CNRS*² *EOST/UMR7516-UNISTRA*³ *OPGC (Observatoire de Physique du Globe de Clermont-Ferrand)***Corresponding Author(s):** thomas.lecocq@seismology.be

The 2018 seismic sequence of Mayotte began the 10 May at 50-60 km east from the island and Mamoudzou (most important city of Mayotte with approximately 70000 inhabitants) with earthquakes of magnitude 3 – 4. The major event with a magnitude of 5.7 (BRGM) took place 5 days after (Mw 5,8-5,9 USGS), preceded the day before by a magnitude 5.2. Until the 15 June (period considered in the study of BCSF-RENAISS), the few stations of the local seismological network recorded more than 1000 earthquakes with 38 of magnitude > 4.9 (BRGM, 2018). The seismicity remained steady until mid-June, with almost daily earthquake of magnitude between 5 and 5,5 and on average about 20 of magnitude > 3.5 with a peak of more than 80 M>3.5 the 1st June. If the intensities (severity of the ground shaking) seemed, in view of the available preliminary information, to not exceed V (EMS-98 scale) for every event in particular because of the epicentral distance (50 to 70 km), the damage reported by the municipalities during the following days, both in level of damage as in number of affected buildings, brought us to activate a field survey with our Macroseismic intervention group (GIM) to analyze the real impact. Considering the impossible distinction of the effects for each event, the objective of this field survey was to establish the level of damage of buildings, according to their vulnerability, produced by the seismic swarm until the date of our investigation in each municipality. This assessment of cumulated damage versus vulnerability at the city scale was then associated to an “equivalent intensity”. These values, despite they cannot be taken into account for scientific studies or seismic scenarios as real EMS98 (severity of ground shaking), they reflect the impact of a seismic sequence on macroseismic observations and allow to help the interpretation of macroseismic data for similar cases in the historical period. We will underline in this presentation the difficulties we had for this specific macroseismic study related to a seismic swarm with several events inducing damages and the difference with a classical estimation of the macroseismic intensities for an event only.

Poster Session 1 / 40

Toward a better characterization of small to moderate earthquakes seismological pattern in Northeastern France

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Seismic risk assessment in intraplate regions with low surface deformation, such as Northeastern France, and its border countries of Germany and Switzerland, faces important challenges related to vulnerability due to the : high density of population, numerous industries with sensitive activities (nuclear power plants, mines, quarry blasting, chemical and bacteriological industries), and fragile historical heritage to protect. However, despite being located at the middle of the western Europe, seismic hazard estimation in our study area remains poorly constrained, especially because of lack of knowledge on active structures' identification and the nature of the processes responsible for earthquakes. Furthermore, the regional seismicity encompasses significant historical and recent earthquakes (intensity up to IX and X), together with a regular activity heterogeneously distributed over the whole region, and affecting all the main geologic domains : the Upper Rhine Graben, the ancient massifs of the Vosges and the Black Forest, the Jura mountains with the molassic basin and the Alps. We focus here on the small events, whose the space time evolution and the statistic analysis are important criteria to characterise the seismic behaviour of the region and its potential seismogenetic structures. By taking advantage of an exceptional, recently densified seismic network (development of temporary stations (2015-2020) in the framework of the European AlpArray project, reinforcing the growing permanent national networks of France, Germany, Switzerland and Belgium), we are building a new seismic catalog following a methodology specifically adapted to this network and its low level of detection, the current regional seismicity and the large amount of waveforms analysed. Doing so, we reduce the magnitude of completeness and access to more accurate hypocentral localizations and magnitude estimations, which are crucial for the seismic event classification and a better characterisation of the seismic behaviour of the region.

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Archeoseismology in Machu Picchu, Paleoseismology and Lacustrine records in Cuzco region as key interdisciplinary approaches for intraplate deformation characterization on the Andean Altiplano

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In South America, human beings are prone to settle along fault scarps. Emblematic among them in Peru, the touristic and tectonic Cuzco region is affected by damaging earthquakes since the Spaniards arrived, as demonstrated by the 1650, 1950 and 1985 events. This area in the high Altiplano, sitting 400km away from the subduction zone, exhibits a combination of strong seismic hazard and high vulnerability through the presence of active fault segments in densely populated areas. The accurate estimation of past effects of previous earthquakes on build heritage is a

key to provide additional data (recurrence, and past impacts) to properly assess the seismic risk in intraplate deformation zones such as the Andean altiplano. Indeed, archeoseismological pioneering studies demonstrated that faulted and disturbed architectural remains can be used as valuable markers to extend the catalog of more classical paleoseismological studies. Prehistoric monumental architecture in Peru goes back to 3000yrs BCE and the construction techniques have been used throughout the country on Machu Picchu and Choquequirao sites among others, proving to be a sustainable resource for the evolution of the south american culture. We plan to map and study the past seismic effects on archeological remains, the construction modes and designs on monumental heritage to complement the evidences of deformation issued from archeological soils, fault trenching and proximal lake coring. Thus we aim to build a catalog prehistoric earthquakes and their induced effects. The overall purpose is to extend the knowledge and time window for the crustal fault activity on the Cuzco-Vilnacota fault system. This work present the first paleo events records from trenching efforts we pursued on the different fault segments and the targeted post glacial lake to core, and monumental building to be studied.

Poster Session 1 / 42

Amateur seismological stations in Belgium and Zeeland

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We report on the installation and maintenance of professional-grade seismic stations by amateurs in Berloz (Belgium) and Oostburg (Zeeland, The Netherlands) and the usefulness of the data provided by their stations.

Poster Session 1 / 43

Seismotectonic markers along the Hockai Fault Zone (East Belgium) – new insights

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The historic 1692 Verviers Earthquake (Ms 6-6.3) represents one of the most significant events in NW Europe, with its supposed epicentral area being located along the Hockai Fault Zone (HFZ) in East Belgium. This, and other seismic events in the past, characterises the 42 km long HFZ as a seismically active zone of multiple fault segments, which also crosses the entire Stavelot Massif. In this work, we present various geomorphological markers that can be used as proxy indicators to characterise the seismotectonic activity of the area. A special focus is laid on recently discovered geomorphological features in the region of Malmédy, i.e. a steep scarp in the orientation of the HFZ adjacent to two ancient landslides. These features have been investigated by various geophysical techniques, notably passive and active seismic measurements (H/V method and seismic refraction) as well as electrical resistivity tomography (ERT). Seismic and electric profiles across the scarp reveal a significant contrast in geophysical properties of soil, confirming its assumed tectonic origin. Results of our field campaign are compared to earlier research of the better known slope failures in the northern segment of the HFZ - the landslides of the Pays de Herve (region of Battice). These slope failures can be essential markers in order to understand not only the geomorphological history of the region, but also to confirm the seismotectonic context of the region.

Session 4 / 44**Endokarst, witness of the sismo-tectonic history**Prof. QUINIF, Yves¹¹ *University of Mons***Corresponding Author(s):** thomas.lecocq@seismology.be

The relations between the karstification and the sismotectonic events can be divided in two great chapters. (1) During karstogenesis, there are relations between tectonic conditions and possibility of karstogenesis. (2) After active evolution of endokarst, we can use the geometry of the endokarstic features and the endokarstic deposits to characterize and date the sismotectonic phenomena.

I. Karstification and geological evolution The knowledge of many karstic features proves that karstification happens during some steps of the geological history and not only as geomorphological phenomena which takes place during the last million years. To make this synthesis, we need to examine the conditions and the modes of the karstification. In the frame of the karstogenesis by ghostrock, the tectonic environment is particularly important. This type of karstification is the same that occurs during the pedogenesis. The weathering of the minerals of the bedrock is sequential following the kinetics of the chemical reactions. In the case of the carbonates, the weathering dissolves preferentially the micritic part of the rock. The sparitic part (fossils, veins, a.s.o.) and the insoluble parts (clay minerals, quartz, oxides, a.s.o.) stay in place. In a first step, this evolution happens at constant volume. The residual alterite occupies bodies like vertical corridors from the top of the massif, or underground bodies: the “pseudoendokarsts”. The tectonic conditions play an important role. The initial permeability is realized in joints in extension because of the tectonics, as well as the permeability of the residual alterite. The genesis of speleological caves happens when a hydrodynamical potential appears generally by tectonic surrection.

II. Recent tectonics events and modification of the endokarstic geometry The connected voids of a karstic system (galleries, pits, chambers) constitute a well know geometry. One can thus characterize perturbations to this geometry, like tectonics events like the action of a fault. If the gallery is always active, one must take into account the erosion processes. In Belgium, a fine example is the Lorette active faults and the setting up of an underground laboratory in the Lorette cave. A team with the ROB and the universities of Mons and Namur has collaborated to this project. Some normal faults deform galleries. Extensometers were installed and operate since 15 years. Those measurements have proved a present continuous slip of this fault zone (0,04 mm/y) which correspond to the geological observations.

III. Recent tectonics events and modification of the endokarstic deposits Deformation of underground deposits, essentially the speleothems, also provides information on recent tectonic events: rupture of a column, apparition on columns of tension gashes, displacement of a stalactite in comparison with the associated stalagmite or formation of a bending in a stalagmite. Dating of broken speleothems by earthquakes gives the possibility to have the interval, in which the break occurred, especially for the soda straws breccia in flowstones. In conclusion, the consequences of tectonic phenomena in caves are proved and are tool for studying those phenomena. A new way of researches is the consequence of earthquakes on the collapses in great rooms, like in the “dome” chamber in the Han-sur-Lesse cave.

Session 1 / 45**The Earthquakes of June 5th, 1443 and August 29th, 1471 in Eastern Europe**Dr. ALEXANDRE, Pierre¹¹ *Royal Observatory of Belgium***Corresponding Author(s):** thomas.lecocq@seismology.be

The seismicity of Eastern Europe before the 15th century is not well known because historical sources (annals, chronicles, etc.) are missing, except in Russia. Numerous claimed earthquakes

in traditional com-pilations were demonstrated as late forgeries in the study of Pierre and Dominique Alexandre (2012).

The first well known general shock is the one of June 5th, 1443. The former work of Labak (1996) is the first useful study of this event because it was realized according to reliable sources. But this author neglects or rejects some data – in particular the Silesian data – and so underestimates the area perceptibility of this earthquake. We drew up a new map of the 1443 shock of which the epicentre was localized in Western Slovakia. The other macroseismic datapoints are located in Austria, Moravia, Bohemia, Silesia, Little Poland and Galicia. Unfortunately data are missing southwards – in the present Hungary – due to lack of sources.

With regard to the earthquake of August 29th, 1471, we wrote in our previous study (2012) that this event took place in the year 1473, according to an Austrian source, the annals of the Melk abbey. But the discovery of a much more precise document modified our point of view: the date of 1471 is the right date. This new document is a very detailed account written by Thomas the Szekler, prior of the Preachers in Brasov (Kronstadt) in Transylvania. In our new map, the macroseismic datapoints of this shock are located in Moldavia, Transylvania, Wallachia, Bessarabia and Crimea. The epicentre is most likely to be localized in the famous area of Vrancea, as already thought by Tatevossian and Albini (2010).

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Improving the databases for seismic hazard analysis in Germany

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Reliable seismic hazard analysis is based on good quality data and models of the distribution of earthquakes in terms of time, space and size and the underlying processes that can explain this distribution. To improve the basis in Germany present work coordinated by BGR focuses on the earthquake catalogue, the paleoseismological database, the database of active faults and a seismotectonic source zonation.

The earthquake database “GERSEIS” contains approximately 50,000 seismic events (ML > 2 or felt) with instrumentally and macroseismological derived parameters from the year 800 until today. We started to re-evaluate important, damaging historical earthquakes, to build a macroseismic database, and to determine moment magnitudes from instrumental and macroseismic data.

The recently established database of paleoseismic evidences in Central Europe “PalSeisDB” documents the records of paleoseismic evidence (49 trenches, 107 soft-sediment deformation, 47 mass movements and 19 other paleoseismological evidences). Currently this database is extended by investigating soft sediment deformation in Northern Germany as possible indications of seismic events in the Quaternary.

We started compiling a database of active faults and seismogenic structures in Central Europe. Current neotectonic evidence will be compiled on the basis of geological, seismic, seismological, geomorphological and remote sensing studies.

To develop a new seismotectonic source zonation, we are collecting relevant geoscientific data and publications. We are developing a concept for the derivation of seismotectonic source zones taking into account the geological development, the neotectonic situation and geophysical data characterizing the seismogenic zones in the crust.

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Towards a protocol of archaeoseismological survey

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There is more in archaeoseismology than just a good story - wrote Manuel Sintubin and co-authors back in 2008 (SRL 79). Observations abound, get published, interpreted and various conclusions are drawn, more or less well-founded. However, due to the nature of excavations and restorations valuable information is lost if not documented properly and in time. Much information is lost due to the fact that we do not have a fixed methodology of this rapidly developing science. Here a scheme of observations is suggested, which is applicable at various sites. The purpose is to record and preserve information, both for immediate interpretation and for reappraisal later. Archaeology is inherently destructive; restoration can be destructive if information is overlooked and annihilated. Recording of damage which might indicate earthquake is of ultimate importance, even if one is not sure about its interpretation. Examples are given from sites in the eastern Mediterranean.

1) Studying single / multiple buildings (landscape archaeoseismology) 2) preserved parts: whole building or foundations only 3) function of building / function of parts / change in function 4) foundation: on solid rock / soft rock / landfill 5) materials used 6) construction method 7) dimensions 8) construction history - succession of building periods (archaeological stratigraphy) 9) search for anomalies (in order from big to small) 10) shear / symmetry of entire building 11) tilt of entire building: intact / damaged / missing parts of building 12) deformation of precise geometry (dome, arch) 13) walls / columns vertical or tilted 14) bent / torn / collapsed walls 15) dropped / shifted / rotated / extruded blocks 16) fracture across single/multiple blocks / walls / entire building 17) undulating floor level 18) change in material / quality of workmanship 19) man-made or nature-made 20) repair / support / restoration / reconstruction 21) reuse of spoiled masonry 22) proof of seismic origin - exclusion of other origins 23) earthquake intensity 24) earthquake date 25) strong motion direction 26) site effects 27) damage at what elevation? - damage on top only or throughout the building? 28) causative fault 29) single / multiple earthquakes 30) is there contemporary destruction nearby? 31) earthquake-resistant construction methods / earthquake culture

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Archaeoseismological potential of the Upper Rheingraben

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Leydecker's (2011) catalogue lists merely two historical earthquakes between 800 AD and 1499 AD in the northern part of the Rheingraben. Archaeoseismological evidence is provided for several damaging earthquakes during Roman times and the Middle Ages.

The Roman villa at Ahrweiler was buried by mudflow. Before 400 AD an earthquake caused liquefaction, which yielded subsidence of floors and walls, created a liquefaction funnel, and injected sand in overlying layers at foundation level.

The Roman Porta Nigra of Trier was built in ca. 170 AD. It was damaged by an earthquake causing keystone drop, shifted and rotated masonry blocks. The damaged gate tower was enclosed by a Christian church in ca. 1040.

It is held that the first, Roman church in Trier was destroyed by fire. However, the Domstein, a fragment of a former granite column of the church, on display in front of the Dom, does not show any evidence for fire. On the contrary, a conspicuous axial fracture indicates that the first church of Trier was destroyed by an earthquake in the early 5th century.

Thermen an der Viehmarkt in Trier suffered a major liquefaction event, causing floor of a Roman swimming pool to collapse and thick walls of the bath to subside. A pool in the Barbarathermen was also heavily damaged by liquefaction.

An earthquake damage during the construction of the Speyer Dom (1030-1061) caused the construction of supporting buttresses.

Reconstruction of the Mainz dom in 1361, following a collapse of the choir vaulting sometime between 1319-1361, left behind an odd central pillar.

Roman military and civilian architecture of the limes along the Rhine, Carolingian masonry constructions, Romanesque and Gothic cathedrals hide multiple proofs of seismicity during the

last two millennia. Further site visits will certainly yield appropriate evidence for past earthquakes along both the western and eastern faults, filling up the temporal gaps in historical and geological data.

Reference

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Historical surface-breaking earthquake in central Europe?

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We analysed morphologically pronounced, NNW-SSE trending Mariánské Lázně Fault (MLF) situated in the western part of the Bohemian Massif (Czech Republic, central Europe). The MLF controls the eastern limit of Cheb-Domažlice Graben. In the northern part it borders the Cenozoic Cheb basin towards mountain front of Krušné hory Mts and intersects with NE-trending Cenozoic Eger rift. The Cheb basin is known for Mid-Pleistocene volcanism, abundant occurrences of mantle-derived carbon-dioxide emanations, and present-day earthquake swarms with maximum magnitude not exceeding Mw 4.0. These present-day swarms are mostly aligned along a NNW-trending fault known only from the foci at the depth with no geological or morphological expression on the surface and which intersects mountain front of the Krušné hory Mts controlled by the MLF, trending NW-SE in the Cheb basin segment. Since no significant recent seismicity or large earthquakes (Mw>6) have been reported for the MLF, we used 3D paleoseismic trenching to look for a large surface-rupturing prehistoric earthquake, which could be responsible for the pronounced mountain range front. We excavated seven trenches and six hand-dug trenches at the site Kopanina with most suspicious morphology related to the MLF zone. The trenches revealed a complex geology and deformation probably as a result of right-lateral transpression during Late Quaternary. Even Holocene colluvia appeared to be faulted, indicating at least two Holocene surface-breaking earthquakes on the MLF with possible minimum magnitude Mw=6.3-6.5. OxCal modelling based on radiocarbon dating of charcoals sampled from the faulted Holocene deposits shows a prehistoric earthquake in the period 1134 BC – 192 BC and the latter one during 792 – 1020 AD. Several candidates for a historical earthquake of the latter period were analysed from the historic earthquakes catalogues. So far it seems that the surface-breaking earthquake that we revealed from the trenching could have matched with the reported historical earthquake that occurred 998 AD. Further investigation on this match is under process. Nevertheless, our paleoseismic study revealed the youngest surface-breaking earthquake in central Europe and the largest one in the Bohemian Massif proven so far. This might have a great implication for seismic hazard for areas with slow-moving faults.

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Impact of historic “key events” on the results of seismic hazard assessment

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The completion of version 2.1 of the magnitude-oriented earthquake catalogue for German and adjacent areas EK DAG - extended Ahorner catalogue (as of December 2014) gave rise to the question of the influence of current catalogue entries (or their changes) and the hazard analyses highlighting them on practical engineering applications. This question was fundamentally extended to the question of the consideration of uncertainties in the entire calculation chain in a modularly structured procedure and by combining current research activities. It was to be accepted that in the context of a damage prognosis based on probabilistic seismic hazard analyses (PSHA) earthquake catalogues provide the basic data, but in the course of the preparation of seismicity models (and the relationships describing the seismic action implemented there) they become a secondary influencing factor, provided that the return periods relevant for the design of general buildings (up to about 2500 years) are considered. The presentations will focus on the impact of different magnitude levels for selected model to give an impression of the state of a currently processed calculation tool, which establishes the connection between probabilistic seismic hazard analysis, site-specific generated soil movement models and damage prognoses for the concrete site and development situation and is thus intended to enable concrete risk statements for existing structures.