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International Workshop on "Active tectonics and dating"

September 14 – 16, 2021

Hybrid format

(Praz-sur-Arly, France - Belambra Club "L'Alisier" & online)

Abstract Book

Talks

Workshop "Active Tectonics & Dating"

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Workshop "Active Tectonics & Dating"

The potential of high-resolution sampling to reconcile OSL and TCN data: study case of the Choushui Tableland (West Central Taiwan)

Rizza Magali[1], Lebrun Brice[1,2], Siame Lionel[1], Braucher Régis[1], Guillou Valéry[1], ASTER Team[1]

[1] *Aix Marseille Univ, CNRS, IRD, INRAE, CEREGE, Aix-en-Provence, France*
[2] *IRAMAT - CRP2A, CNRS - Université Bordeaux Montaigne, France*

☒ Talk
☐ Poster

The determination of fault slip rate is often inferred from dating of Quaternary, deformed geomorphological surfaces affected by fault activity. For this reason, cosmogenic and luminescence methods are widely applied to date the emplacement of geomorphic markers, but each method relates to a different geomorphic process. While the Terrestrial Cosmogenic Nuclides (TCN) method generally dates the exposure duration of the rock surface to cosmic rays, the Optically Stimulated Luminescence (OSL) method provides burial duration of the sediment after deposition. Age differences between these two methods may relate to the erosion-transport-deposition processes experienced by the sediment prior its final deposition but combined may provide new insights into the processes affecting alluvial landforms.

Our case study is located in Western Foothills of Central Taiwan, south of the Choushui River. There, slip on the Changhua blind thrust fault has caused the eastward tilt of a wide flight of fluvial terraces but slip rates on frontal faults are still debated due to large epistemic uncertainties in dating alluvial surfaces with OSL and TCN methods. To achieve a finer chronology of the deposits, a high-resolution sampling strategy has been deployed leading to a direct and unique comparison between OSL and TCN dating methods. Taking advantage of a natural exposure, we collected 10 samples for ^{10}Be dating completed by 11 OSL samples (6 dated) along a 7m-depth profile. The depth distribution of ^{10}Be concentrations show a complex depositional history with at least two depositional sequences, modelled to be deposited around 38.7 ka and 50 ka.

As previous works have shown the difficulties of OSL dating in Taiwan, particular attention has been paid to luminescence characteristics of quartz and potential dosimetry issues. Our OSL analysis are in good agreement with ^{10}Be and previous ^{14}C dating and reveal three depositional units, dated between ~9 ka and 66 ka. The three alluvial units are evidenced by ICP-MS and ICP-OES measurements and their limits are confirmed by different OSL signal characteristics and variations in dosimetry.

This study shows that it is informative to have an exhaustive, detailed, and direct comparison between dating methods on a single depth profile and allow a more detailed understanding of the long-term rates of the Changhua Fault.

Keywords : Optically Stimulated Luminescence, Cosmogenic isotopes, Quaternary dating, alluvial deposits.

Workshop "Active Tectonics & Dating"

Holocene Tectonic and Climatic activity on the Andean Altiplano

Coupling High resolution DEMs and Exposure dating methods for extreme events knowledge in Pachatusan, Peru

Audin L. [1], Zerathe S. [1], Litty C. [2], Telenchana E. [1], Delgado F.[4], Carcaillet J. [1], Robert X. [1] Gérard B.[3], Benavente C.[4], Rosell L.[4], Garcia B. [4], Palomino A.[4]

[1]*ISTerre, IRD, CNRS, Grenoble, France*
[2]*ISTerre, CNES, Grenoble, France*
[3]*GET, Toulouse, France*
[4]*INGEMMET, Lima, Peru*

☒ **Talk**
☐ Poster

The increasing availability of high-resolution Digital Elevation Models (DEM) reveals numerous evidences of tectonic geomorphology in Slowly Deforming Continental Regions. Among them, the high Andean region is characterized by case examples of scarps and tectonic offsets that are not yet considered for seismic hazard assessment in the Altiplano. We here present evidence of series of post-Last Glacial Maximum (LGM) tectonic activity in the high Andean region in Peru. With both high-resolution DEMs and Terrestrial Cosmogenic Nuclide dating, we noticed that the normal faults systematically offset late Quaternary glacial features above 4000 m a.s.l., among them perfectly preserved morainic fronts from Huaytapallana to the Cuzco-Vilnacota or the Parina fault systems across the Altiplano. For most cases, the fault morphology is dominated by a nearly continuous 10 to ~50 m-high scarps, locally accompanied by antithetic fault scarps and hanging wall graben. The glacial features are not dated yet. These moraines are typically estimated to have been deposited between ~10 and 45 ka, which is not accurate enough to constrain tectonic slip rates. To constrain the timing of reactivation and rates of those faults, we sampled for TCN dating (1) the different generation of moraines cut by the faults and (2) some vertical profiles directly along the fault free-face. Sampling paleoseismic free faces or poorly consolidated moraines is challenging as they may have experience erosion. Moreover, quartz are rare in the Andean volcanic lithologies that are sampled on Tambomachay and Pachatusan sites and we used alternative mineral-TCN pair such as the ^{10}Be-feldspar to date the geomorphic markers. Based on the precise vertical offsets and newly dated moraine ridges, we estimate that the minimum average postglacial slip rates along the normal fault systems varied from ~0.1–0.3 mm/yr over the Holocene at least, i.e., rates are one order of magnitude higher than those reported in former studies. Also, the maximum postglacial slip rate along faults is consistent with the short-term paleoseismic trends where available. The newly produced dataset of moraines ages non-only demonstrates the interest of paired mineral-TCN dating, but also contributes to improve our understanding of past glacier advances over the Altiplano region as it was most probably covered by ice during the LGM. In most of the high Andes in Peru or Ecuador, studying tectonic activity and quantifying Holocene crustal deformation that have long been supposed to be seismically quiet could be eased by the identification of systematic and ideal glacial markers such as post LGM moraines. Finally, such studies indirectly support the efforts to trace back the LGM deglaciation patterns in the equatorial High Andes.

Keywords : Slowly Deforming Continental Regions, Last Glacial Maximum, Active tectonics, Normal fault and moraines, Altiplano, TCN-pair dating, Andes

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Luminescence dating as a potential geochronometer for the deformed alluvial fan sediments in eastern Himalayas

Chandreyee Chakrabarti Goswami[1*], Manoj Jaiswal[2], Puneet Mourya[2], Atul Singh[3]

1. Institute of Rock Structure and Mechanics, Prague, Czech Republic
2. Indian Institute of Science Education and Research, Kolkata, India
3. Inter University Acceleration Centre, New Delhi, India.

*chandreyee.goswami@irsm.cas.cz

☒ Talk

☐ Poster

The deformed alluvial fan sediments of the eastern Himalayan foothill region are key indicators to understand the tectonic activity of that area during Quaternary time. This area is marked by identified fault scarps, tilted and unpaired terraces, straight or sudden changes of river courses. The area falls under the Seismic Zone IV, and marked as Jaldhaka or Garubathan recess (Mukul et al.2014, Dasgupta et al. 2013). Here, the Main Boundary Thrust (MBT) separates crystallines of Lesser Himalayan Sequence and Quaternaries, whereas Himalayan Frontal Thrust (HFT) is within the Quaternary. There is also an unsolved problem regarding the absence of Siwalik or Siwalik equivalent sediments (Mio-Pliocene) in this area.

There is a hitherto unsolved question about the timing of deposition and the deformation of the fan sediments. Till the 1st decade of this millennium only three C-14 dates were available from this area (~300 km^2) which are all younger than 40ka (Guha et al. 2007) and were also not very deterministic about the tectonic history due to possibility of recycling from older deposits giving ambiguity of strata/sample correlation. In recent years, Optically Stimulated Luminescence (OSL) Dating has been used frequently to understand the time of formation as it dates directly the last day light exposure of the sediment and thus providing age of the burial event of the sediment (Goswami (Chakrabarti) et al., 2012, 2013, 2014, 2019; Singh et al. 2016, 2017). These sediments can also be related with different tectonic pulses on the identified faults (MBT and HFT).

In the C^{14} dating methods, though the Accelerator Mass Spectroscopy method does not count the β-particles like conventional counting method and a very small amount of sample is required, it has also not been able to generate reliable ages beyond 45 ka due to certain limitations (Song et al., 2015). Moreover, the sediments of the study area may not contain datable organic material.

Although the exposed rock surfaces and boulders in a strath terrace, surface exposure ages (e.g. ^{10}Be, ^{26}Al) have gained popularity, these areas with much anthropogenic activity are not suitable for it too.

In this circumstance, OSL dating is very useful as it uses the ubiquitously available quartz and feldspar for dating. The Blue-Green OSL on quartz can be used to date the samples up to 200 ka, which depends upon the environmental dose rate in the vicinity of the sample. The Infrared luminescence (IRSL) of feldspar can be used to get ages up to 500 ka, but the feldspar may suffer from an inbuilt problem of anomalous fading therefore quartz is preferred over feldspar. However, with improved methods of IRSL which allows the corrections of ages of anomalous fading affected samples, this has been seen as a potential tool to date the sediments from Himalayas.

A large number of OSL dates from the sediments spread over this area spatially and temporally shows the fan surface started its formation before 171ka and has been deformed in many pulses, last being around 5ka. These results have completely changed the previous idea of much younger fan sediments and their deformation history. It has also helped in identifying the timing of activation of faults related to the HFT and identified backthrust in the excavated trench perpendicular to the fault scarp.

Keywords : Eastern Himalayan Foothills, HFT, Quaternaries, OSL dating

Workshop "Active Tectonics & Dating"

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Cave deformation as a datable environmental earthquake effect: insights to paleoseismicity of the NE Bohemian Massif

Jacek Szczygieł[1,2] Artur Sobczyk[3] Helena Hercman[4] Maciej Mendecki[1]

[1]1*Institute of Earth Sciences, University of Silesia, Sosnowiec, Poland. jacek.szczygiel@us.edu.p*

[2] *Department of Geology, University of Vienna, Austria*

[3]*Institute of Geological Sciences, University of Wrocław, Wrocław, Poland.*

[4]*Institute of Geological Sciences, Polish Academy of Sciences, Warszawa, Poland.*

☒ Talk

☐ Poster

In the tectonically stable part of Europe, singular events strong enough to produce fault rupture have been recorded so far. One of such the early Holocene earthquakes has been documented along significant, ca. 200-km long, tectonic line in Central Europe - Sudetic Marginal Fault (SMF). Less than 20 km south of the SMF in the Niedźwiedzia Cave, several dozen broken and fallen stalagmites, stalactites, and flowstones have been documented, the largest of which are nearly 0.6 m in diameter and around 2 m in height. Often, there are also massive underground collapses of thickness, reaching up to several meters. Multiphase speleothem damage and cave passage collapse were dated with U-series methods, revealing five breaking events: (1) 320-306 ka, (2) 253-236 ka, (3) 162-158 ka, (4) 135-132 ka, and (5) >21 ka. Events 1, 3, and 4 are robustly constrained, whereas events 2 and 5 are of less certainty.

The damage occurred independently from climatic conditions both in cold and warm periods; hence frost and ice activity can be likely excluded. Observed damage of the cave ceiling, walls and also the floor points that deformations might be earthquake effect. To quantify the probable seismic source size, we compared a scant record of historical and prehistoric earthquakes from the region with ground motion models and speleothem failure criteria.

The proximity of the SMF and documented earthquakes M>6 in the Late Pleistocene and Holocene points to the conclusion that the SMF can produce peak ground acceleration (PGA) amplitudes at a distance between the fault and the cave, forcing the speleothems to break.

Plausible seismogenic sources are faults limiting the Upper Nysa Kłodzka Graben from the east. Although there is no historical data that would help estimate the seismic hazard herein, the short distance between the cave and faults (from several hundred meters to 8 km) would reduce the attenuation effect, and even moderate earthquake suffice to damage speleothems. Reported Th-U dated events of in-cave collapses are the first Middle to Late Pleistocene geochronological-documented marks of paleoseismic activity at the northern flanks of the Bohemian Massif.

The work is a result of research project no. DEC-2017/01/X/ST10/00375 financed from the funds of the Polish National Science Center.

Keywords : Speleoseismology, Paleoseismology, U-series dating, Seismic hazard, Bohemian Massif, Sudetic Marginal Fault

Workshop "Active Tectonics & Dating"

Surface rupture and earthquake recurrence along the Tsetserleg fault (Mongolia): insights from UAV-based photogrammetry and paleoseismology

Yacine Benjelloun[1], Yann Klinger[1], Laurent Bollinger[2], Solène Antoine[1], Ganbold Baatarsuren[3], Yungbeom Cheon[4], Jin-Hyuck Choi[4], Ganzorig Davaasuren[1,3], Steven L. Forman[5], Angela Landgraf[6], Sodnomsambuu Demberel[3]

[1] *Université de Paris, Institut de Physique du Globe de Paris, CNRS, F-75005 Paris, France,* [2] *CEA, DAM, Arpajon, France,* [3] *Institute of Astronomy and Geophysics, Ulaanbaatar, Mongolia,* [4] *Korea Institute of Geosciences and Mineral Resources, Daejeon, South Korea,* [5] *Baylor University, Waco, TX, United States,* [6]*NAGRA, Wettingen, Switzerland*

☒ Talk
☐ Poster

In July 1905, two M ~ 8 earthquakes occurred along four distinct strands of the Bulnay fault system, in northwestern Mongolia. This is one of the largest and best-preserved continental strike-slip sequences, and it offers a unique opportunity to study how the complex geometry of fault zones modulates their seismic behavior at various time scales. We focused our investigation on the Tsetserleg oblique branch, where the first event of 1905 nucleated, to characterize the 3D coseismic deformation, and get first time insights on its slip-rate and paleoseismic record. We acquired drone images on selected sites along the Tsetserleg rupture, favoring sites with structural complexities and significant surface fracture development. With the high-resolution topographic dataset produced, we finely mapped the fracture network associated with the rupture. Using crack width measurements as a proxy for surface slip, we obtained average values ranging from 2 to 3 m for the horizontal coseismic slip, with no significant vertical displacement. These results agree with previous analyses of horizontally offset markers. Our detailed mapping allowed us to identify distinct features corresponding to successive steps of the 1905 rupture propagation, and to cumulative deformation from past events. By dating a laterally offset channel riser with the IRSL method, we constrained a ~0.4 mm/yr horizontal slip-rate on the fault. We identified at least three paleo-events in two fault-perpendicular trenches, which we dated with 15 OSL samples. The penultimate event may correspond to a similar sequence as in 1905, although the average recurrence time is much larger than on the Bulnay fault. Our findings show that complex fault systems can be characterized by a significant variation of the rupture patterns over successive seismic cycles.

Keywords : active fault, Mongolia, strike-slip, fault branch, paleoseismology, earthquake sequence

Workshop "Active Tectonics & Dating"

Quaternary earthquakes and active deformation in soft sediments along intracontinental fault zones in the central Pannonian Basin

Krisztina Sebe[1], Gyula Konrád[1], Gábor Csillag[2, 3], Tamás Telbisz[4]

[1] *University of Pécs, Department of Geology and Meteorology, 7634 Pécs, Ifjúság ú. 6., Hungary; sebe@gamma.ttk.pte.hu*

[2] *Institute for Geological and Geochemical Research, Research Centre for Astronomy and Earth Sciences, Budaörsi út 45, 1112 Budapest, Hungary*

[3] *ELKH-ELTE Geological, Geophysical and Space Science Research Group at Eötvös University, Pázmány Péter sétány 1/c, 1117 Budapest, Hungary*

[4] *Department of Physical Geography, Eötvös Loránd University (ELTE), Pázmány Péter sétány 1/C, 1117 Budapest, Hungary*

☒ Talk
☐ Poster

In connection with nuclear power plant extension, research has been carried out to assess Quaternary seismicity and active deformation in central Hungary, in an area with relatively strong historical earthquakes. Field investigations of Quaternary sediments and topography, digital elevation model analysis, boreholes and paleoseismological trenching was applied to reveal signs of past earthquakes and vertical surface movements. OSL and radiocarbon dating was used to gain information on the timing of deformations and on earthquake recurrence times.
Linear features in the topography are dominantly of aeolian origin, very few topographic steps may be linked to faults. A slight folding of the modern surface was detected in the late Quaternary, after the last glacial maximum. Seismically induced deformation structures were found along faults mapped from seismic reflection profiles and localised near the surface with shallow S-wave seismics. Along less significant faults sand injections, liquefaction-related deformations, water escape structures and surface subsidence was observed. Major fault zones were characterised by 1) arrays of uniformly dipping extensional fractures, parallel with the underlying faults, sometimes with collapse structures; 2) clastic dykes (sand injections); 3) asymmetric, inclined or overturned folds with a uniform vergence and 4) water escape structures. Liquefaction-induced deformations can have been produced by earthquakes of a minimum magnitude 5. No vertical or strike-parallel relative displacement of the sand bodies on both sides of the fractures could be detected, thus most of the documented fractures are probably not direct continuations of fault branches, but instead are dilation fractures or sand injections formed indirectly by earthquake waves above the faults. A possible explanation is that displacement at depth is accommodated within thick loose sediments near the surface, in a wide stratigraphic interval. Deformed horizons occurred in fluvial and aeolian sands and silts dated between 19-29 ka and indicated earthquake recurrence times of 400–1500 years.

Keywords: seismite, soft-sediment deformation, earthquake recurrence time, tectonic geomorphology

Workshop "Active Tectonics & Dating"

Landforms and sedimentary structures associated to a Holocene intraplate poly-phase strike-slip fault: Kopce Hill, Outer Western Carpathians

Ivo Baroň[1], Rostislav Melichar[2], Filip Hartvich[1], Michal Bíl[3], Tomáš Pánek[4], Martin Šutjak[2], Jiří Janál[5], Petr Tábořík[1], Tomasz Goslar[6], Regis Braucher[7]

[1]*The Institute of Rock Structure and Mechanics, Czech Academy of Sciences, V Holešovičkách 94/41, 182 09, Praha 8, Czech Republic;*

[2]*Faculty of Science, Masaryk university, Kotlářská 2, 611 37 Brno, Czech Republic;*

[3]*Faculty of Science, Palacký University Olomouc, Křížkovského 511/8, 779 00 Olomouc, Czech Republic;*

[4]*Faculty of Science, University of Ostrava, 30. Dubna 22, 701 03 Ostrava, Czech Republic;*

[5]*National Heritage Institute, Riegrovo náměstí 3228/22, 767 01 Kroměříž, Czech Republic;*

[6]*Poznan Radiocarbon Laboratory, Rubież 46, 61-612 Poznań, Poland;*

[7]*Centre Européen de Recherche et d'Enseignement des Géosciences de l'Environnement (CEREGE), Bâtiment Pasteur, Europole Mediterraneen de l'Arbois BP80, 13545 Aix-en-Provence cedex 4, France;*

☒ Talk
☐ Poster

Landforms associated with active-fault surface ruptures are usually less persistent because they often develop in soil or soft sediments and might frequently be overprinted or misinterpreted by similar gravitational mass movement structures. Thanks to available high-resolution airborne Lidar DTM, however, we were able to detect a recently active polyphase strike-slip fault with a system of landforms attributed to its surface rupture near the village of Lidečko, the Flysch belt of the Outer Western Carpathians, that resembled and were previously interpreted as a complex deep-seated rockslide.

The area is composed of 5-10 m thick competent sandstone and conglomerate beds interbedded with weak shale and claystone of the Luhačovice member that form a large NNE-SSW trending anticline as an excellent marker of the subsequent present-day brittle deformation. Several generations of pressure ridges alongside extensional crevice-type caves developed during alternating dextral and minor sinistral strike-slip phases that also offset an artificial prehistoric circumvallation of the Lusatian age.

Structural data such as fault surface orientation, striation, and sense of movement revealed the fault kinematics and relative age at available natural and man-made outcrops. Deeper fault architecture was studied using the electric resistivity tomography while specific fault-related sedimentary structures were documented in two paleoseismological trenches. Especially the trench in the river plain excellently exposed sedimentary and co-seismic structures of the fluvial and lacustrine sediments. Cosmogenic radionuclide Beryllium-10 exposure dating at rocky scarps near caves as well as radiocarbon dating of deformed lacustrine sediments constrained ages of several fault reactivations from 3.3 ka to 1.2 ka BP that comprised displacements from a few decimeters to first meters. The preliminary pilot data on the fault origin, tectonic controls, and paleoseismological aspects are discussed in the paper.

Keywords: intraplate active fault, surface rupture, landforms, sedimentary structures, radiometric dating;

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Soft-sediment deformations in a periglacial eolian sand sheet reveal latest Pleistocene activity of the Vienna Basin Transfer Fault

Michal Šujan[1], Samuel Rybár[1], Edit Thamó-Bozsó[2], Tomáš Klučiar[1,3], Matúš Tibenský[4], Krisztina Sebe[5]

1– Department of Geology and Paleontology, Faculty of Natural Sciences, Comenius University in Bratislava, Ilkovičova 6, 842 15 Bratislava, Slovakia; michal.sujan@uniba.sk

2– Mining and Geological Survey of Hungary, Stefánia út 14, 1143 Budapest, Hungary, bozso.edit@mbfsz.gov.hu

3– MM Revital, Šustekova 10, 851 04, Bratislava, tkluciar@gmail.com

4– Department of Mathematics and Descriptive Geometry, Faculty of Civil Engineering, Slovak University of Technology in Bratislava, Radlinského 11, 810 05 Bratislava, Slovakia, matus.tibensky@gmail.com

5– Department of Geology and Meteorology, University of Pécs, Ifjúság ú. 6, Pécs 7624, Hungary, krisztina.sebe@gmail.com

☒ Talk
☐ Poster

Paleoseismological research focused on the intensity and recurrence intervals of earthquakes trough geological time is of primary importance for the prediction of geohazards related to seismic events. It is done routinely by dating the exposure of fault scarps using in situ produced cosmogenic nuclides, by dating the deposition of strata progressively deformed by active faults, but also by the identification of soft sediment deformation structures (SSDS) interpreted to be triggered by a seismic shock. However, most studied liquefaction SSDS can be caused by a number of triggers and interpretation is commonly ambiguous.

Here we present a study of SSDS, namely fractures and collapse wedges (Fig. 1), which are rarely documented in publications, and associated further deformations. They were observed in an eolian sand sheet exposed in the Bažantnica sandpit near the town Plavecký Štvrtok, in the eastern Vienna Basin. The several dm wide collapse wedges are sharply delimited from the surrounding sand and are filled by blocks/slices of the surrounding succession. The most common features, simple fractures have dip angles of 45° to 85° degrees and along them sand layers are commonly bent down. All wedges exhibit obvious signs of downward movement of material. The two sides of either collapse wedges or fractures show no or in a single case very small vertical offset. Both wedges and fractures are planar, without significant variation in orientation. Wedges and fractures are grouped in horizons and are topped by an erosional surface. The fractures are oriented systematically in N-S to NE-SW direction. The horizons crosscut by wedges commonly include layers with a chaotic structure, created through the

disruption of the original sediment into cm- to mm-sized fragments. Less frequently folded layers also occur, with series of cm- to dm-amplitude folds. Fold shapes vary from symmetrical to asymmetrical and from upright to overturned.

Luminescence dating revealed that the deformed sand sheet accumulated during the MIS2, partly during the Last Glacial Maximum. The paleoclimatic studies imply a discontinuous permafrost or seasonal frost for the region with mean annual precipitation of 300–490 mm (*Ruszkiczay-Rüdiger and Kern, 2016: Quat. Int. 415, 241-252*). The described conditions imply that the sand sheet strata could have behaved cohesively to some degree because of frozen capillary water, what may have allowed strongly inclined fractures to form without the collapse of the sand above the crack. The locality lies just along the boundary fault of the Zohor-Plavecký Basin, a graben along the Vienna Basin Transfer Fault System, which experienced significant subsidence during the Quaternary. The systematic orientation of the brittle deformations and their position relative to the paleotopography excludes slope failure and cryoturbation as formative processes. The described characteristics indicate seismic shock as a potential cause of forming the cracks on the surface. The distribution of the deformed horizons within the dated succession implies a tentative estimate of earthquake recurrence interval in the order of ~500 years per event. The lack of sand injections indicates earthquake magnitudes below 5.

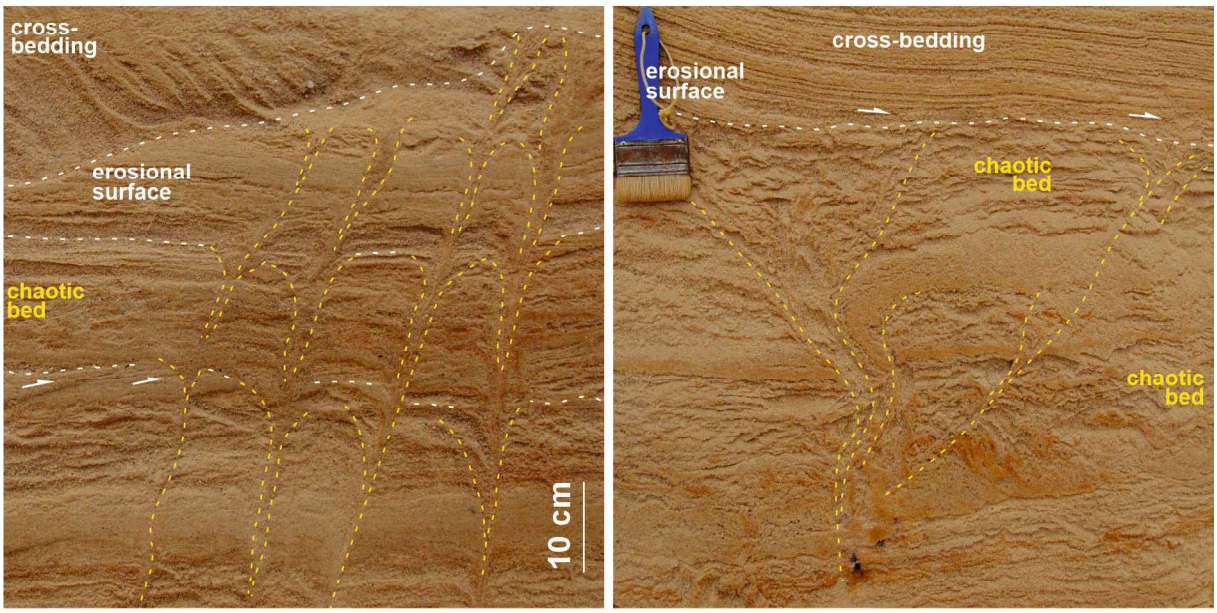

Figure 1: Examples of collapse sand wedges. White symbols indicate primary structures, yellow ones represent deformations.

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

Magali Riesner[1], Lucilla Benedetti[1], Stéphane Baize[2], Matthieu Ferry[3], Jules Fleury[1], Stefano Pucci[4], Francesca Cinti[4] and Daniela Pantosti[4]

(1) Aix Marseille Univ, CNRS, IRD, INRAE, CEREGE, Aix-en-Provence, France
(2) Institut de Radioprotection et sureté Nucléaire, Fontenay-aux-Roses, France_
(3) Géosciences Montpellier, France
(4) Centro Nazionale Terremoti, Istituto Nazionale di Geofisica e Vulcanologia (INGV), Rome, Italy

☒ Talk
☐ Poster

Long-term fault escarpments are built by the accumulation of individual earthquakes producing incremental surface ruptures on the fault releasing crustal tectonic loading. Cumulative escarpment studies have revealed a spatial slip variability along active faults as well as a temporal variability with the alternation of phases of intense seismic activity over a short period of time followed by long periods of quiescence. Understanding this spatial and temporal slip variability on individual faults and over a complex fault system provide a better knowledge of co-seismic rupture extents essential for estimating past earthquakes magnitude and seismic hazard assessment.
Up to now, most studies have focused on a short timeframe, over very few seismic cycles, making it difficult to apprehend the persistence of rupture barriers and cumulative slip distribution. Here, within the frame of the ANR EQTIME (ANR-19-CE31-0031) we aim at quantifying the slip variability over several timescales ranging from a few months to a few million years on the same fault system.
The active Apennines range in Italy provide an excellent context to study the long-term relief build-up by incremental earthquakes. The range is ~400 km long and ~100 km wide, currently undergoing extension at 3-4 mm/yr on NW-SW striking normal faults. Our study focusses on the ~50 km long Liri fault, SW of the Fucino basin. The fault is located at the contact between Cretaceous limestone in its footwall and Mio-Pliocene flysch sediments in its hangingwall. Because of the important anthropization and the sparse Quaternary deposits in this area, designing a strategy for (1) dating the surfaces to quantify the long-term slip rate and (2) trenching the recent alluvial deposits to retrieve paleoearthquakes has proven challenging.
Detailed mapping of the fault trace on high-resolution Digital Elevation Model (DEM) from UAV-acquired images, Pleiades images and Lidar together with field observations revealed a variation in the morphological expression of the fault north and south of an important wind gap located at Capistrello. To the north, the faut trace is ~16 km-long located on the eastern side of ~2km-wide limestone ridge, reaching ~1300m asl elevation. Two bends in the fault trace, made of ~5km long segments, can be observed with the fault strike varying between N115° and N140°. In this northern section, the fault scarp appears subtle and we did not

observe Quaternary deposits on the hanging wall. In the 30 km-long southern section, the cumulative scarp composed of numerous splays is evidenced by a sharp trace, offsetting several morphological surfaces. It is located on the eastern side of a higher relief reaching 1700m asl elevation. Six bends are observed in this section of the fault, separating 3 to 10 km-long segments striking between N110° and N160°. We identified three potential trenching sites with Quaternary deposits potentially affected by the fault and surveyed three additional sites where unconsolidated fanglomerates appear offset by a few meters to almost 30 m cumulative displacement. These two types of markers will enable to constrain both the recent fault activity, its slip-rate and associated past earthquakes, and to quantify how the displacement varies along the fault.

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Combined on-fault and off-fault paleoseismic evidence of the last rupture of a hitherto unknown active subaquatic fault segment in Lake Iznik (Turkey).

R. Gastineau[1,2], J. de Sigoyer[1], P. Sabatier[2], S.C. Fabbri[3], F.S. Anselmetti[3], AL. Develle[2], M. Şahin[4], S. Gündüz[4], F. Niessen[5] and A. C. Gebhardt[5]

[1]Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, IRD, IFSTTAR, ISTerre, 38000 Grenoble, France
[2]EDYTEM, Université Savoie Mont-Blanc, Université Grenoble Alpes, CNRS, Le Bourget du Lac, France
[3]Institute of Geological Sciences and Oeschger Centre for Climate Change Research, University of Bern, Baltzerstrasse 1+3, 3012 Bern, Switzerland
[4]Bursa Uludağ Üniversitesi, Fen-Edebiyat Fakültesi, Arkeoloji Bölümü, Görükle, Bursa, Turkey
[5]Alfred Wegener Institute (AWI) Helmholtz Centre for Polar and Marine Research, D-27568, Bremerhaven, Germany

☒ Talk
☐ Poster

Lake Iznik (NW Turkey), is bordered by the middle strand of the North Anatolian Fault (MNAF), whose seismic activity is debated because of its quiescence during the instrumental period. In contrast, significant historical activity is documented by several chronicles over the last two millennia.

This study aims to get a new insight into its long-term seismicity and its tectonic setting. Lacustrine sediment cores reveal fourteen earthquake-induced turbidites associated to historical seismic events during the past two millennia. Bathymetry and high-resolution seismic reflection data allow describing two hitherto unknown subaquatic active fault structures (the South Boyalica and Iznik faults), belonging to the MNAF system. Sediment cores sampled on both sides of the Iznik Fault document an event deposit and a sedimentary unit vertically offset of ~ 40 cm interpreted as the last rupture during the 1065 CE destructive earthquake. Older events are supposed on this fault more than a thousand years ago. Further studies will help to estimate the horizontal coseismic offset of this oblique-slip fault and the calendar of older ruptures. The current seismic gap of thousand years on this segment greatly increases the seismic hazard in this region and must be considered in the seismic risk assessment of the NAF system.

Keywords: North Anatolian Fault, Lake sediment, Fault activity, Earthquake, Turbidite, paleo-seismicity.

Workshop "Active Tectonics & Dating"

The uranium-thorium chronology of the uplifted terraces in the Gulf of Aqaba: new insights for the problem of diagenetic alteration.

Matthieu Ribot[1,2], Yann Klinger[1], Edwige Pons-Branchu[2], Sigurjón Jónsson[3], François Thil[2], Arnaud Dapoigny[2], Matthieu Boccas[4], Asmodée Galy[4,5], Norbert Mercier[5], Christophe Pecheyran[4]

(1) Université de Paris, Institut de physique du globe de Paris, CNRS, Paris, France.
(2) Laboratoire des Sciences du Climat et de l'Environnement (UMR CEA/CNRS/UVSQ), Gif-sur-Yvette, France.
(3) King Abdullah University of Science and Technology, Thuwal, Saudi Arabia.
(4) Institut des Sciences Analytiques et de Physico-Chimie pour l'Environnement et les Matériaux, CNRS, Pau, France.
(5) Centre de Recherche en Physique Appliquée à l'Archéologie (IRAMAT – CRP2A)

☒ Talk

☐ Poster

The establishment of a reliable chronology for corals is a major issue for different fields of researches, including climate, sea level changes, and tectonics. Since the first measurements and attempts for coral dating using mass spectrometry in the end of the 80s, the Uranium-Thorium (U/Th) chronometer is the most commonly used dating technics as it provides precise ages for the past 500 to 600 kyr. However, one main issue with fossil corals, and more specifically with marine uplifted terraces dating, is the diagenetic alteration that can result in biased ages due to open system behavior and departure or arrival of chemical elements. One of the mechanisms classically involved is the aragonite to calcite transformation.

In order to better assess the U/Th chronology of fossil corals, we propose to think backwards and to test the use of Tectonic and eustatic curve to constrain dating uncertainties due to diagenetic alteration, of uplifted terraces.

In March 2017, we collected 78 corals from the uplifted terraces along the shore of the Gulf of Aqaba. After U/Th processing, 18 samples provided consistent and robust ages for the three first levels of terraces. Our results agree with recent studies and reveal that the elevated terraces are formed during the interglacial periods. However, the results illustrate that less than ~25% of the samples provide meaningful ages to estimate the tectonic uplift, although the X-Ray Diffraction (XRD) analyses alone would suggest that at least 55% of samples could be used for dating, based on the proportion of aragonite. Observation of thin sections for selected samples reveals that some of the corals presenting acceptable aragonite values (> 70%), present in fact clear signs of diagenesis with at least two crystallization phases. The first crystallization phase corresponds to the pristine skeleton of the coral, while the second crystallization phase is more complex as it corresponds to the crystallization of minerals in the porosity and/or recrystallisation of the coral skeleton. This simple observation evidences that the XRD analysis do not permit to identify all diagenetic alterations, as it does not allow discrimination between primary and secondary aragonite. We also determined that in most samples, primary aragonite is still present in coral samples, although it would require high-resolution sampling technics to extract material, which might not exceed the size of a pinhead.

Following these observations, we derived several criteria to validate U/Th ages in the Gulf of Aqaba, that are not limited to mineralogical determination, uranium content or isotopic composition, but include the agreement with eustatic curves and tectonic evolution.

In order to refine the understanding of diagenetic phenomena and its impact on coral ages, we used laser ablation (LA) coupled with mass spectrometry in order to try to differentiate alterated and pristine zones within the same sample: LA-MC-ICPMS for the $^{87}Sr/^{86}Sr$ determination to be compared with Strontium Isotope Stratigraphy (SIS) and LA-HR-ICPMS for the U/Th analysis. The analytical precision achieved for strontium analysis does not allowed to use SIS for relative age determination, but allowed us to identify the incorporation of exogeneous strontium within alterated zones. Preliminary results obtained using LA-HR-ICPMS for the U-series, allow us to produce an age map of the coral with the differentiation of zones with different U contents, U isotopic compositions and different apparent ages.

Keywords: Gulf of Aqaba; Corals; U-Th; Diagenesis.

Workshop "Active Tectonics & Dating"

Vertical slip rates along the Mt Vettore Fault (Central Apennines, Italy) constrained by 36Cl exposure dating of glacial features

Lea Pousse-Beltran[1,2], Lucilla Benedetti[1], Jules Fleury[1], Paolo Boncio[3], Valéry Guillou[11], Bruno Pace[3], Anne Socquet[4], Magali Rizza[1], Irene Puliti[3], Aster team[1]

[1]*Aix Marseille Univ., CNRS, IRD, Coll. France, CEREGE, Aix-en-Provence, France*

[2] *Now, at School of Earth and Ocean Sciences, University of Victoria, Victoria BC, Canada*

[3] *University "G. d'Annunzio", Chieti-Pescara, Italy*

[4] *Université Grenoble-Alpes, Université de Savoie Mont-Blanc, CNRS, IRD, IFSTTAR, ISTerre, 38000 Grenoble, France*

Email list: Léa Pousse-Beltran: leapousse@uvic.ca , Lucilla Benedetti: benedetti@cerege.fr , Jules Fleury: fleury@cerege.fr , Paolo Boncio : paolo.boncio@unich.it , Valéry Guillou: guillou@cerege.fr , Bruno Pace: bruno.pace@unich.it , Anne Socquet: anne.socquet@univ-grenoble-alpes.fr , Magali Rizza: rizza@cerege.fr , Irene Puliti: irene.puliti@unich.it , Aster team

☒ Talk
☐ Poster

In the Central Apennines (Italy), slip rate assessments based on offset morphotectonic markers on the main branches of fault systems and encompassing several seismic cycles (> 10 ka) are sparse. This is particularly true for the Monte Vettore-Monte Bove fault system which triggered the 2016-2017 seismic sequence. In this study, we focus on the glacial valley below the Mt Porche (Valle Lunga) using the coseismic mapping of the surface rupture for the 2016 earthquakes, high-resolution DEM and cosmogenic dating. Offset measurements were made using a 5-cm resolution DEM obtained through a drone survey and constrain a i) fault scarp height of 15.5 ± 1.4 m, ii) a minimum cumulative offset of 32-40.5 m and iii) a maximum cumulative offset of 39-46 m. Samples were collected from the Valle Lunga terminal moraine at 1710 m asl and yield 36Cl exposure ages of 12.7 + 2.2/-1.9 ka while the flat abraded surface located on top of the tectonic scarp yield 36Cl exposure ages of 23.4 + 5.3/-4.3 ka. Assuming the offset started to accumulate when climate conditions allow its preservation, we constrain a vertical slip rate of 1.2 ± 0.2 mm/yr along the main branch of the Mt Vettore normal fault. This rate is higher than the ones previously obtained from trenches along secondary splays of the Mt Vettore-Mt Bove and on the Norcia fault systems. Besides, the yielded chronology for the last glacial maximum in that area at ~23 ka is in good agreement with the timing previously proposed for the LGM in the Apennines.

Keywords :

Workshop "Active Tectonics & Dating"

Integral slip rates and simultaneous ruptures between fault branches in a paleoseismic transect across the Alhama de Murcia Fault, SE Spain

O. Gómez-Novell[1], M. Ortuño[1], J. García-Mayordomo[2], Eulàlia Masana[1], Raimon Pallàs[1], Juan Miguel Insua-Arévalo[3], José Jesús Martínez-Díaz[3], Thomas Rockwell[4], Stéphane Baize[5]

[1]*RISKNAT, Facultat de Ciències de la Terra, Universitat de Barcelona, 08028 Barcelona, Spain (octgomez@ub.edu)*

[2] *Instituto Geológico y Minero de España, 28760 Tres Cantos, Spain*

[3]*Departamento de Geodinámica, Estratigrafía y Paleontología, Facultad de Ciencias Geológicas, Universidad Complutense de Madrid, 28040 Madrid, Spain*

[4]*Department of Geological Sciences, San Diego State University, 92182 San Diego, California, EUA.*

[5]*Institut de Radioprotection et Sûreté Nucléaire – Seismic Hazard Division (BERSSIN), 92262 Fontenay-aux-Roses, France*

☒ Talk
☐ Poster

The Alhama de Murcia Fault (AMF) is one of the most active faults in the Eastern Betics Shear Zone (EBSZ), a prominent fault system that accommodates an important part of the shortening from the Eurasia-Africa convergence in the Iberian margin. Here, we present the results from a comprehensive paleoseismological study across four of the five fault strands that conform the AMF in one of its central segments (Lorca-Totana; LT). This study aims to: i) obtain representative slip rate data for the whole segment, previously inferred from a single branch, ii) complete paleoearthquake chronosequences and recurrences, and iii) identify potential rupture synchronicity between sites. In the LT segment, the fault is divided into at least five strands accommodating deformation in a partitioned style. The two frontal strands limit a frontal pressure ridge (S-AMF and F-AMF), the northwesternmost (N_1-AMF) bounds the mountain range, and the two remaining are intermediate branches forming a pop-up structure ($N_{2(a\ and\ b)}$-AMF). Eight paleoseismic trenches, including a 7 m deep enlargement of a previous trench, were excavated in four of the strands across a transect of the fault zone, unveiling recent Quaternary activity in all of them. Trench vertical and lateral slip analysis combined with OSL and radiocarbon dates allowed to obtain a total net slip rate of 1.55 $^{+0.14}/_{-0.18}$ mm/yr (four branches), considerably higher than previous estimations (0.9±0.1 mm/yr). The slip rate evolution constrained with numerical dates shows fluctuations over time that might suggest super-cycle patterns. The frontal pressure ridge of the system records the most recent and complete activity of the transect, while the northern branches are affected by poorer sedimentary resolutions. In S-AMF, one of the completest paleoearthquake records of the Iberian Peninsula has been identified, with 17 events for the last ~100 ka. This yields an OxCal-derived short-term recurrence of 4.3±0.4 kyr for the last 31 ka (7 events), consistent with the one in F-AMF (3.1±1.4 kyr) for the last 18 ka (5 events). The last 5 events in both branches since 15-18 ka are compatible in time, suggesting possible synchronic ruptures. In this framework, their similar recurrences and nearly identical vertical slip rates (~0.26 mm/yr) support the feasibility of such rupture behavior in the pressure ridge. The present integral paleoseismic study has revealed to be an important step for a more representative characterization of the paleoseismic parameters of the AMF. Acquiring refined and well-constrained fault parameters is thus encouraged as it is a key practice to improve the fault-based seismic hazard assessments.

Keywords: paleoseismology, Alhama de Murcia Fault, slip rate, paleoearthquake, event chronosequence, rupture synchronicity

Workshop "Active Tectonics & Dating"

Insights on fault reactivation during the November 11, 2019, Mw4.9 Le Teil earthquake in south-eastern France, from a joint 3D geological model and InSAR time series analysis

L. Marconato [1], P. H. Leloup [1], C. Lasserre [1], R. Jolivet [2,3], S. Caritg [4], R. Grandin [5], M. Métois [1], O. Cavalié [1, 6], L. Audin [7]

[1] *Univ Lyon, Univ Lyon 1, ENSL, CNRS, LGL-TPE, F-69622, Villeurbanne, France*
[2] *Laboratoire de Géologie, Département de Géosciences, École Normale Supérieure, PSL Université, CNRS UMR 8538, Paris, France*
[3] *Institut Universitaire de France, 1 rue Descartes, 75006 Paris, France*
[4] *Bureau de Recherches Géologiques et Minières (BRGM), France*
[5] *Université de Paris, Institut de physique du globe de Paris, CNRS, F-75005 Paris, France*
[6] *Université Côte d'Azur, IRD, CNRS, Observatoire de la Côte d'Azur, Géoazur, France*
[7] *ISTerre, Univ. Grenoble Alpes, CNRS, IRD, Grenoble, France*

☒ Talk
☐ Poster

The 2019, Mw4.9 Le Teil earthquake occurred in south-eastern France, causing substantial damage in this slow deforming region. Field observations, remote sensing and seismological studies following the event revealed that coseismic slip concentrates at shallow depth along a ~5 km long rupture associated with surface breaks and a thrusting mechanism. We further investigate this earthquake by combining geological field mapping, 3D geology, InSAR time series analysis and a coseismic slip inversion.

From structural, stratigraphic and geological data collected around the epicentre, we first produce a 3D geological model of the region surrounding the rupture using the GeoModellerTM software. Our model includes the geometry of the geological layers and of the main faults, including the La Rouvière Fault, the Oligocene normal fault that ruptured during the earthquake.

We generate a time series of surface displacement from Sentinel-1 SAR data ranging from early January 2019 to late January 2020 using the NSBAS processing chain. The spatio-temporal patterns of surface displacement for this limited time span show neither clear pre-seismic signal nor significant postseismic transient deformation. We extract the coseismic displacement pattern from the InSAR time series, highlighting along-strike variations of coseismic surface slip. The maximum relative displacement along the Line Of Sight is up to ~16 cm and is located in the southwestern part of the rupture.

We invert for the slip distribution on the fault from the InSAR coseismic surface displacement field. Constraining our fault geometry from the geological model, acceptable fault dip ranges between 55° and 60°. Our model confirms the reactivation of La Rouvière fault, with reverse slip at very shallow depth and two main slip patches reaching respectively 30 cm and 24 cm of slip, both around 500 m depth. We finally discuss how the 3D fault geometry and geological configuration may have impacted the slip distribution and propagation during the earthquake.

This study is a step to reassess the seismic hazard of the many faults similar to the La Rouvière fault along the Cévennes fault system, in a densely populated area hosting several sensitive nuclear sites.

Keywords : Continental neotectonics; Seismic cycle; Le Teil earthquake; 3D geological modelling; InSAR time series; Source inversion

Workshop "Active Tectonics & Dating"

Dating abandoned fluvial terraces with cosmogenic ^{3}He to determine the present uplift of the Massif Central within the northeastern termination of the Cévennes fault system.

N. Cathelin[1,2], S.Baize[1], JF.Ritz[2], PH.Blard[3], P.Voinchet[4], P.Antoine[5], M.Cushing[1], C.Larroque[6]

[1] IRSN, Institute of Radiological Protection and Nuclear Safety, Fontenay-aux-roses, France.

[2] Géosciences Montpellier, Univ. Montpellier, CNRS, Univ. Antilles, Montpellier, France.

[3] CRPG, CNRS, Université de Lorraine, 54500 Vandœuvre-lès-Nancy, France.

[4] Laboratoire Histoire naturelle de l'Homme et Préhistorique, CNRS-MNHN-UPVD, Paris, France.

[5] Laboratoire de Géographie Physique, Environnements Quaternaires et actuels, Meudon, France.

[6] Géoazur, Université Côtes d'Azur, CNRS, Observatoire de la Côte d'Azur, IRD, Valbonne, France.

☒ Talk
☐ Poster

The 11-11-2019 Mw 4.9 Le Teil earthquake in southern France was associated with a 5 km long surface rupture along the La Rouvière fault (LRF), an ancient Oligocene normal fault belonging to the NE-SW trending Cévennes fault system (CFS) (Ritz et al., 2020). This intra-plate event has highlighted the possibility in metropolitan France, that faults not mapped as active faults so far, could be reactivated. Moreover, paleoseismological investigations carried out after the event suggest that the LRF had already produced at least one surface-rupturing event during the past 17ka (Ritz et al., EGU 2021), thus demonstrating the need of carrying out more paleoseismological works within the French large fault systems. The present study was performed in the line of those new results. The aim is to analyze the general deformation across the NE termination of the CFS through fluvial markers of the Escoutay River, which watershed crosses perpendicularly the CFS. We used in situ-produced cosmogenic ^{3}He to date several abandoned fluvial terraces containing basaltic pebbles. The dating of an alluvial surface at Saint Thomé, located immediately to the north of the la Rouvière fault allows estimating a mean incision rate of 0.51 ± 0.03 mm.y^{-1}. This result is consistent with recent results obtained within the southern part of the CFS (Malcles, 2021), and suggests that the Massif Central is presently uplifting. In progress dating of two other alluvial surfaces along the Escoutay valley, located northwest and southeast of the CFS northeastern termination, respectively, should allow analyzing if, in addition of this uplift, a differential vertical movement is occurring across the CFS, attesting of its Quaternary reactivation. This reactivation could be related to the Massif Central uplift, maybe also combined with the present Alps uplift, as suggested by recent works (Olivetti *et al.*, 2020; Vernant *et al.*, 2013; Malcles *et al.*, 2020).

Keywords: Terraces – ^{3}He dating – Incision – Uplift - Morphotectonics

Workshop "Active Tectonics & Dating"

Location of the main shock and aftershocks of the Le Teil earthquake (2019/11/11, Mw 4.9) in the geological context of the Southeast Basin edge (France).

Christophe Larroque[1], Maxime Godano[1], Bertrand Delouis[1], Françoise Courboulex[1], Stéphane Baize[2], Jean-François Ritz[3], Elif Oral[1], Jean-Paul Ampuero[1].and Jérémy Billant[1].

1 Géoazur Université Côte d'Azur-CNRS, France
2 Institut de Recherches et de Sureté Nucléaire (IRSN), France
3 Géosicences Montpellier, Université de Montpellier-CNRS, France

☒ Talk
☐ Poster

The Rhone Valley was strongly shaken by a Mw 4.9 earthquake on November 11, 2019. This earthquake is typical of moderate events that occur regularly in metropolitan France. However, it has characteristics, in particular surface rupture and very high ground acceleration for this magnitude, that prompt the community to review the implications of such events in hazard assessment.
One of the characteristics of this earthquake is the very shallow focal depth (< 2 km). However, the permanent and temporary seismological stations existing at the time of the earthquake do not allow us to locate precisely the epicenter and the focal depth. In order to better specify the hypocenter, we analyzed the impact using or not the post-seismic stations on the location of an aftershock and by considering hypocenters compatible with the geometry of the fault responsible for the earthquake.
Another characteristic of this earthquake is the very few number of aftershocks recorded despite the 45 seismometers installed in the week following the earthquake. Standard earthquake search analyses of continuous signals from mid-November 2019 to mid-January 2020 were initially able to detect only a small number of aftershocks of magnitude ≥ 1.8. This number was significantly increased by the use of a Template Matching method that eventually detected 130 aftershocks of magnitude ≥ -1.5. These aftershocks were then carefully located by the double-difference method.
We compare the location of the focus and the aftershocks with the geology of the La Rouvière fault zone. The rupture was initiated in the Mesozoic sedimentary cover, we discuss the precise location of the focus in the lithology and its relation to the fault as well as the distribution of aftershocks in the fault wall versus the fault roof.

Keywords : Le Teil earthquake, La Rouvière fault, focal depth, aftershocks, template matching

Workshop "Active Tectonics & Dating"

Morphotectonic study of the Rémuaz Fault, Aiguilles Rouges

Pauline André[1], Riccardo Vassallo[1], Jean-Louis Mugnier[1], Léa Courtial-Manent[1] , Hervé Jomard[2], Marielle Collombet[1], Laurent Métral[1], Marie-Pierre Doin[1]

[1] *Institute of Earth Sciences (ISTerre), Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS, IRD, IFSTAR, 38000, Grenoble, France* [2] *IRSN, Fontenay-aux-Roses, France*

☒ Talk

The low tectonic strain rates in the Western Alps make the identification of active structures difficult as well as the characterization and the quantification of the processes at the origin of the seismicity. The knowledge of active faults is still largely incomplete, but even with a low rate of deformation destructive earthquakes can occur. However, the millenary action of the deformation can be observed by the formation of cumulate morphologies, often associated with the reactivation of inherited geological structures.

In the Aiguilles Rouges Massif (Chamonix-Mont-Blanc Valley) the Rémuaz fault shows scarps and morphologies rarely observable in the Alps and is a suitable study zone for the estimation of postglacial deformation through morphotectonic and paleosismological studies. This fault will be the object of the field-trip associated with the workshop.

The Rémuaz fault can be considered as a segment of a larger fault zone, the Vallorcine Fault which is one of the main seismically active structures in France at the scale of the last century. Two Mw>4 earthquakes were associated to this fault system in 1905 (Mw 5.3, Cara et al., 2017) and in 2005 (Mw 4.5, Fréchet et al., 2011), and repeated seismic swarms estimated lasting several months occurred during the last 30 years.

We studied the fault trace that is visible in the morphology and runs linearly through the eastern flank of Aiguilles Rouges massif. Several glacial landforms are crossed by the fault such as polished bedrock and moraines, creating scarps across them. In this context, the limiting factors for observing tectonic deformations at surface are the markers degradation by hillslope processes, the presence of forest patches hiding large parts of the fault trace, and confusion with gravitational deformations. An airborne LiDAR survey, performed in 2012 by CEMAGREF/INRAE for studying avalanche corridors, allowed obtaining decimetric resolution Digital Elevation Models. This high-resolution DEM allowed revealing the microtopography all along the fault trace highlighting a dominant dextral strike-slip component compatible with a tectonic origin for the post-glacial deformation.

We will present the last advances in fault characterization, in particular 1) the mapping of offset moraines to be dated in order to determine a postglacial slip rate, and 2) the preliminary results of a paleoseismological analysis across the fault.

Keywords : morphotectonic, paleoseismogy, Chamonix Valley

Workshop "Active Tectonics & Dating"

Late Holocene initiation of a normal scarp linked to a deep rock slope failure revealed by ^{10}Be surface exposure dating (Chamonix valley)

Léa Courtial-Manent[1], Swann Zerathe[1], Jean-Louis Mugnier[1], Julien Carcaillet[1], Pauline André[1], Riccardo Vassallo[1], Ludovic Ravanel[2], Marie-Pierre Doin[1], Jean-François Buoncristiani[3]

[1] *Institute of Earth Sciences (ISTerre), Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS, IRD, IFSTAR, 38000, Grenoble, France ; [2]EDYTEM, USMB, CNRS – France ; [3]Biogéosciences, Dijon – France*

☒ Talk

Normal scarps are morphological expressions of brittle rock failure that can be observed in extensive tectonic context but also along with deep-seated landslides. Scarps thus are particularly well-suited structures to use cosmic ray exposure dating methods.

We studied a pluri-kilometers long rock slope failure newly identified in the Aiguilles Rouges massif (Chamonix valley, France). Thanks to a high-resolution LiDAR DEM and field works, we mapped morpho-structures including scarps, tension cracks and counter-scarps. We identified distinct stages of gravitational evolution. In some places, vertical offsets can reach tens of meters and trenches some meters of width. The evidence of gravitational activity (boulders displacements from analyses of archive satellite images) and the relatively fresh scarp outcrops suggest a sub-actual activity. These observations are in agreement with the ground displacement rates of a few millimeters per year estimated by InSAR time series between 2014 and 2018. Extensometric measurements along some trenches are also ongoing.

We sampled two vertical profiles along the top scarps (11 samples) to define the chronology (both the initiation and evolution) of the slope failure using ^{10}Be surface exposure dating. Glacially polished surfaces cut by these gravitational scarps were also sampled to determine glacial retreat timing as well as to constrain the pre-exposure ^{10}Be inheritance.

Our results highlight a significant time lag between the last evidence of glacial activity (~17 - 12 ka) and the initiation of the slope failure that happened 2 to 3 ka ago (depending on the inheritance schemes). This suggests that the glacial debuttressing would not be the main driving factor. The close proximity with the active fault of La Rémuaz could be another hypothesis for the initiation of the rock slope failure in the Aiguilles Rouges massif.

Keywords: deep slope failure, scarp dating, ^{10}Be terrestrial cosmogenic nuclide, Chamonix valley

Workshop "Active Tectonics & Dating"

Geological investigations of the Maurienne valley Swarm (2017-2019)

Dorian Bienveignant[1], Hugo Dutoit[1], Jérôme Nomade[1], Gael Janex[1], Stéphane Schwartz[1], Christian Sue[1/2], and Philipe Guéguen[1].

[1] *ISTerre, Université Grenoble Alpes, CNRS, Université Savoie Mont-Blanc, IRD, Université Gustave Eiffel*

[2] Chrono-Environnement Besançon, OSU THETA, Université Bourgogne-Franche-Comté.

☒ Talk
☐ Poster

In 2017-2019, a seismic swarm was triggered in the Maurienne valley (French Alps), with more than 5000 events detected by the regional SISmalp network (Gueguen, 2021, Minetto, in prep).

The "La Chapelle" swarm located in the Maurienne valley (French western Alps, External Crystalline Massif) presents a particularly interesting framework for the study of deformations linked to the active Belledonne fault system (Thouvenot, 2003). In the hypocentral zone, the morphological pattern and geological studies clearly show faults and structures in accordance with the deeper and active fault plain highlight after hypoDD relocation (Gueguen, 2021).

A kilometer scale strike slip fault is locally oriented N60 and dipping close to vertical in north direction could be the “surface equivalent” of the fault pointed out by seismic activity. On the edge of the massif, some small faults compatible with a normal movement are observed. We complete field analysis by a photogrammetry survey to characterize and complete fault zone recognition. The presence of striated faults on the surface allows a study of the paleo-stresses put into play during their formation. This fault area visible at the surface presents clearly a dynamic comparable with seismological results (Gueguen, 2021). This fault system visible on the field, is the upper and inactive surface part of the active fault revealed by the swarm location. The tectonic context seems to be the same since the formation of the fault zone highlight in our study and is partly responsible of the actual geomorphology.

Keywords : Seismic swarm, External Crystalline Massif, active tectonics, geomorphology.

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Workshop "Active Tectonics & Dating"

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

Manzanares Pablo[1,2], Bollinger Laurent[2], Rizza Magali[1], Klinger Yann[3], Siame Lionel[1], Bellier Olivier[1]

[1] *Aix Marseille Univ, CNRS, IRD, INRAE, CEREGE, Aix-en-Provence, France*

[2] *CEA, DAM, DIF, F-91297, Arpajon, France*

[3] *Université de Paris, Institut de physique du globe de Paris, CNRS, Paris, France*

☒ Talk
☐ Poster

The Lambesc 1909 Mw 5.5-6.0 earthquake is the largest instrumental earthquake recorded in metropolitan France. Previous studies have demonstrated that the 1909 earthquake likely happened on the Trevaresse thrust system. Along the frontal Ermitage fault segment, one paleoseismic study shows that successive earthquakes ruptured the ground since the Pleistocene (*Chardon et al., 2005*). But return periods and ages of paleo-earthquakes are still debated due to lack of dating controls. Moreover, this paleoseismic observation is located at the eastern end of the fault system and the mapping of active faults westward and associated earthquake activities remain largely unknown due to poor morphotectonic expression in the field and more limited work than what was undertaken by previous teams along the eastern end.

In this study, using high-resolution topographic data (1-m resolution) obtained from an airborne Lidar survey, we map different morphological scarps and morphotectonic features along the entire front of the Trevaresse Range. This work, controlled by field observations along 13.5 km-long, reveals that the Trevaresse fault system is more complex than previously mapped and can be subdivided into 19 distinct fault segments clearly expressed in the landscape, as well as 14 more uncertain segments. Similarly, to what was found at the eastern end of the Trevaresse Range, and despite significant lateral variations of fault orientation and surface expression, the fault system is composed of fault strands developing at the toe of the main Trevaresse fold and more frontal strands breaching colluvial or alluvial deposits a few hundreds of meters southward.

These frontal fault strands and affected Quaternary deposits represent potential targets for future paleoseismological studies that are planned in the framework of the TREVARISK project. New excavations may reveal ancient ruptures and participate to the dating of recent surface ruptures and provide constrains on the return periods of earthquakes in the region.

Keywords : Active faults, earthquakes, LiDAR, Provence, seismic scarp, paleoseismology

Reference :

Chardon, D., Hermitte, D., Nguyen, F., & Bellier, O. (2005). First paleoseismological constraints on the strongest earthquake in France (Provence) in the twentieth century. Geology, 33(11), 901-904.

Workshop "Active Tectonics & Dating"

Cotentin seismicity and Tectonic inheritance

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

[1] *Normandie Univ, UMR CNRS 6294 LOMC, Université Le Havre Normandie -France*
[2] *EA 4253 LUSAC, CNAM-INTECHMER, Cherbourg-en-Cotentin-France*
[3] *IUEM, UMR CNRS 6538, Géosciences Océan, Université de Bretagne Occidentale, Plouzané-France*
[4] *IRSN, BERSSIN, BP17, 92262 Fontenay-aux-Roses, France*

☒ Talk
☐ Poster

The North Armorican Domain exposed in the Cotentin peninsula and the Normano-Breton Gulf is part of the NW European Cadomian orogen that later recorded in its northern part Variscan deformation. This highly eroded polyphase orogenic domain currently experiences low to moderate intraplate seismicity expressed by shallow earthquake swarms.

This regional seismicity is thus assumed to be partly controlled by inherited structures. The concept of structural inheritance has been addressed in the COCOTIER project (INSU/TELLUS/SYSTER) initiated in 2020. This research combines different data, such as high-resolution offshore imagery (bathymetry), onshore-offshore IGN/SHOM data (BDAlti, RGEAlti, LiDAR data and Litto3D) and bathymetric records (R/V Haliotis (IFREMER) BATHAGUE 2008, 2010 and COCOTEC 2019). These data are compiled to obtain land-sea digital elevation models (DEM), further constrained by available geological data, which emphasize the intricate morphotectonic pattern of the West Cotentin offshore area including the Jersey island.

The instrumental seismicity (RéNaSS, LDG, SI-Hex) and historical activity (FCAT-17, SisFrance) have been combined in unique catalogue which indicates a significant seismic activity with high local magnitude ML 4.9 (Mw 4) in 2014 located offshore SW Jersey islands. In addition, more than 46% of the earthquakes in this region have an estimated moment magnitude (Mw) higher than the magnitude of the completeness Mc 2. Furthermore, some other earthquakes experienced remarkable epicentral intensity, such as Coutances 1853 (VI-VII), Cherbourg 1889 (VI), Jersey 1927 (VI), whereas Jersey 1926 earthquake reached an epicentral intensity of VII MSK-64.

Analysis of P-wave first motion polarities recorded by RESIF and BGS seismic networks about earthquakes that occurred between 2014-2015 in Jersey and 2020 in Coutances supplies focal mechanism solutions showing a strike-slip component. The corresponding active faults may be either N150°-oriented Variscan structures or N70°N-oriented Cadomian shear zones, hence illustrated the concept of structural inheritance.

Keywords:

Cotentin, Structural inheritance, Bathymetry, Seismicity, Active fault

Workshop "Active Tectonics & Dating"

Investigating recent seismotectonic activity of the Haubourdin fault in the Mélantois anticline area (Northern France) using LiDAR dataset and GPR survey

GRAVELEAU Fabien[1], CHANIER Frank[1], WATREMEZ Louise[1], OUCHAOU Rachid[1], AVERBUCH Olivier[1], REYNAUD Jean-Yves[1]

[1] *Univ. Lille, CNRS, Univ. Littoral Côte d'Opale, UMR 8187 - LOG - Laboratoire d'Océanologie et de Géosciences, F-59000 Lille, France*

☒ Talk
☐ Poster

North of France belongs to a moderately active seismotectonic area across which several – likely active – structures are identified (i.e. onshore, along the Artois hills, and offshore, along Dover Strait). A few tens of kilometers south of the 1.2 millions inhabited Lille European Metropolis, the ~50-km-long, sub-vertical and N110°E-directed Haubourdin Fault is considered as potentially active during Quaternary times, according to the French Institute of Radiological Protection and Nuclear Safety (IRSN) database. The Haubourdin Fault strikes roughly parallel to the E-W open Mélantois Anticline that folds the Upper Cretaceous chalk and the underlying Paleozoic basement. The Mélantois Anticline mainly developed during the Tertiary reactivation of deep basement structures, located at the northern front of the Variscan fold-belt. Its recent activity is suggested by a decrease in the thickness of the Quaternary fluvial deposits of the Deûle river, which crosses the fold axis.

To investigate and document the possible neotectonic activity of the Haubourdin Fault, we analyzed the morphology from a high-resolution topographic dataset (LiDAR). We extend the topographic analysis slightly eastward (i.e. Belgium) along the Rumes Fault, which might be connected to the Haubourdin Fault. Our analysis has identified three intriguing topographic features along the mapped Haubourdin and Rumes Faults. All these features are strikingly aligned along the N110°E trend. On the French side, these consist in two topographic scarps, with several meters throw in the Haubourdin-Sainghin-en-Mélantois region, and with a 1.5 m throw in the Wannehain region, near the Belgian border. On the Belgian side, near the Rumes city, we have identified a peculiar drainage anomaly with clear evidences of headward erosion and transient state evolution. All features could suggest a recent surface uplift, although a simple lithological effect cannot be discarded.

To document the subsurface geometry of the Wannehain scarp, we surveyed a ground-penetrating radar (GPR) profile with 200, 80 and 20 MHz antennas. Our GPR results do not allow to identify a clear near-surface fault signal. However, a 25-30m deep structure could be suspected in the basement. Both our topographic and geophysical results are compared to our 3-D geological model of the Mélantois Anticline that we have been building with the MOVE software, from boreholes and geophysical datasets, in collaboration with the French Geological Survey (BRGM).

In conclusion, our topographic analysis of two high-resolution datasets along the Haubourdin Fault (in France) and Rumes Fault (in Belgium), has brought out intriguing morphological features that might call for a recent activity along these faults. Unfortunately, our GPR preliminary investigations do not allow to discriminate 1) a neotectonic or 2) an erosional (lithological) origin for one observed scarp. These preliminary results calls upon further investigations, including digging paleoseismological trenches, to confirm/infirm the hypothesis of neotectonic activity of the Haubourdin-Rumes fault.

Keywords : Topographic scarp, Northern France, Haubourdin Fault, Rumes Fault, LiDAR, GPR