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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

Posters session

Workshop "Active Tectonics & Dating"

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Workshop "Active Tectonics & Dating"

Update of the fault network geometry within the substratum of the Eastern Channel-Straight of Dover by acquisition of recent high resolution seismic data: towards a better assessment of the seismic risk.

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☐ Talk
☒ Poster

The eastern English Channel-Straight of Dover (Détroit du Pas-de-Calais) area is characterized by an overall moderate instrumental seismicity. Few significant earthquakes have been documented in the recent history such as the one of 1580 (of presumably 6 Mw magnitude) that led to severe destructions in Calais. In this area heavily impacted by human activities (European-scale routing network, nuclear power plants, extraction, development of offshore wind farms, offshore cable laying, etc.), the recurrence of an earthquake of such a magnitude could have dramatic effects. The knowledge of the inherited fault network within the substratum of the Eastern Channel-Straight of Dover area is thus a major pre-requisite to progress in the assessment of the regional seismic risk. The present-day morphology of the eastern English Channel results from major deformations in the Mesozoic (i.e. Upper Jurassic-Lower Cretaceous rifting) and Cenozoic times (i.e. far-field accommodation of Pyrenean-Alpine shortening) that formed upon a highly-heterogeneous basement structured during the northern Variscan thrust front development (Upper Carboniferous, ca 310 Ma). This multiphase tectonic inversion process led ultimately to the formation of a large uplifted area, the Weald-Boulonnais anticline, separating two topographic depressions, the Dieppe-Hampshire syncline to the south and the Flanders low-land to the north. This WNW-ESE trending eroded culmination across the English Channel, outcrops on land along the Opal Coast, where several E-W faults have been identified. In order to prevent possible risks, especially in coastal areas, characterize and map the tectonic structures offshore this area are necessary. The recent acquisition of very high-resolution seismic data (SPARKER) during the TREMOR 1 & 2 campaigns (2014 & 2017) and the annual GEOBAS campaigns (2016 to 2020), off the coast of Boulogne-sur-Mer, enables producing a new detailed view of the geological structures of the substratum and re-evaluating the connections between structures observed onshore and offshore. On a large scale, the area shows an alternation of about E-W trending faults controlling related-folds developed either as positive tectonic inversion uplifted zones (the Cap Gris-Nez and Boulogne anticlines for the main significant contractional structures) or growth synclines during basin development (for example along the Slack-Epitre fault). To the south of the study area, the post-rift unconformity between the highly faulted Jurassic terrain to the north and the slightly deformed Cretaceous (Late Aptian-Upp. Cretaceous) terrain to the south is well documented. In more detail, we will present here a focus on the onshore and offshore geometries of the Cap Gris-Nez and Slack-Epitre faults. The Cap Gris-Nez structure appears as a buttress fold type deformation zone against a set of pre-existing normal faults developed in relay. The Slack-Epitre fault identified on land extends only shortly at sea (about 1.5 km to the coast-line) as it appears to be shifted 1.5 km to the north due to a transverse poorly documented N30° trending fault. The Slack-Epitre fault appears to be slightly inverted, displays an about 50 meters vertical shift and shows peculiar fluid outflow characteristics.

Keywords : English Channel, seismic risk, high-resolution seismic imaging, Weald-Boulonnais anticline, tectonic inversion

Workshop "Active Tectonics & Dating"

Investigation and dating of some Displacements on Doruneh Fault

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The Doruneh left-lateral strike-slip fault is the second longest fault systems in Iran. This fault is 700 km long, stretching from the Afghanistan-Iran border to the central Iran desert. Despite of its length, position in the convergence zone between the Arabian and Eurasian plates and its seismic potential, no major recent or historical earthquakes are recorded on this fault. Therefore, study on this fault is very important for evaluation of its seismic hazard. In our study, we used the available Landsat images, aerial photographs, topography maps, geological maps and field work data to identify and estimate the amount of displacements of rivers, geology units, and some alluvial fans along this fault. Considering three branches for this fault, the amount of the river displacements, suggests that the main branch between 57˚00′ and 58˚50′E, is more active than the other parts. Several slip rates have been determined using different methods for some parts of this fault ranging from 2 to over 8 mm/yr. We suggest further geomorphological marker offset dating and geodetic methods in the same regions and other parts of the fault to estimate, compare the slip rate of different branches, and extract more information on this important fault.

☐ Talk
☒ Poster

Keywords: Displacement, Slip rate, Activity, Doruneh fault, Iran

Workshop "Active Tectonics & Dating"

Title Recent tectonics near the South Kabyle fault (eastern Algeria): Seismicity, Neotectonic investigations

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☒ Poster

We examine evidences of a recent tectonic activity in northeastern Algeria. It is concerning the Pliocene and Quaternary deformations in front of the South Kabyle fault (SKF). This is a Miocene regional thrusting delimiting the internal zones of external zones of Eastern Maghrebides chain, along the transverse of Constantinois.

Knowing that the geological domain of Constantinois is subject recurrently to moderate seismicity. The last earthquake (August 7th 2020, Ms= 4.9) which has shacked Mila region, is the most important event afterward the strongest earthquake occurred since the instrumental period; ie., Ain Smara earthquake (October 1985, Ms= 6.0).

We investigate in frame of SKF by make use a combination of remote sensing, field prospecting. We present the morphological features discriminating the Pliocene landscape, Quaternary rising and the deformation (folding, faulting) affecting the Pliocene deposits.

We suspect that the SKF as being the source of weakly seismicity in the northern Constantinois. In this fact, its classification as supposed active fault has a seismotectonic implication in seismic hazard assessment.

Keywords: Seismicity, neotectonic indications, Miocene thrust, Constantinois chain

Workshop "Active Tectonics & Dating"

Temps longs et temps courts des instabilités gravitaires profondes : contribution à la connaissance des phénomènes pour la géstion de l'aléa en montagne alpine.

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☐ Talk
☒ Poster

Les Deep Seated Gravitational Slope Deformation (DSGSD) se définissent comme un ensemble de massifs rocheux caractérisés par un mouvement généralement lent et pouvant affecter tous les versants d'une vallée ou d'une chaîne de montagnes (Agliardi et al., 2001, 2009 ; Panek et Klimes ., 2016). Cette instabilité profonde est identifiée dans de nombreux cas comme la zone d'origine d'autres aléas naturels importants comme les glissements de terrain : exemple du glissement de terrain de La Clapière dans les Alpes Maritimes (BigotCormier et al., 2005). Les DSGSD représentent un objet important que nous devons comprendre afin d'anticiper tous aléas gravitaires leurs étant associés. En effet, de nombreux facteurs qui pourraient être à l'origine ou contrôlant l'évolution des DSGSD ont été identifiés comme par exemple l'héritage structural, le climat ou l'activité tectonique (Agliardi 2000 ; 2009 ; 2013 ; Jomard 2006 ; Sanchez et al., 2009 ; Zorzi et al., 2013 ; Panek et Klimes., 2016 ; Ostermann et Sanders., 2017 ; Blondeau 2018). L'évolution à long terme et à court terme des DSGSD est encore mal connue mais représente un point important pour prédire le niveau de risque de chacun d'entre eux. C'est dans le but de mieux comprendre l'évolution à court terme (<100 ans) et à long terme (>100 ans) des DSGSD des massifs alpins français et le lien avec l'occurrence des glissements de terrain, que ce projet de thèse est développé. L'objectif principal de ce projet, est de proposer des modèles d'évolution du DSGSD définissant des clés d'interprétations afin de comprendre l'évolution future des déformations et de localiser les zones susceptibles d'initier d'autres aléas. La zone d'étude du Queyras dans les massifs alpins français a été choisie car elle représente une zone de lacunes d'étude des DSGSD. Cette zone présente également l'avantage d'avoir une faible diversité lithologique permettant de simplifier l'identification des facteurs influençant l'évolution des DSGSD. Une analyse géomorphologique sur données satellitaires et au sol est réalisée pour localiser les DSGSD et caractériser leur structure. Plusieurs datations (14C, 10Be ou 36Cl) seront réalisées pour reconstituer l'histoire de ces objets et comprendre les facteurs qui ont contrôlés leurs évolutions. Grâce à la photo-interprétation des données satellites et aériennes, 30 DSGSD ont été identifiés dans le secteur du Queyras. Ces 30 objets ont été reconnus par l'utilisation d'un ensemble de 6 morphologies couramment rencontrées dans les DSGSD et définies et synthétisées par de nombreux auteurs (Agliardi et al., 2001, 2009, 2013 ; Panek et Klimes., 2016 ; Crosta et al., 2013 ; Blondeau 2018 ; Zorzi et al., 2013 ; Sanchez et al., 2009 ; Gutiérrez-Santolalla et al., 2005 ; Hippolyte et al., 2006, 2009, 2012.). D'autre part, une sélection de 8 objets représentatifs des DSGSD du Queyras a été faite pour la réalisation d'études cartographiques, structurels et de l'évolution de la déformation plus précises. Ces dernières sont complétées par des données et observations issue de trois périodes de terrain dont la synthèse est en cours d'élaboration.

Keywords : Géomorphologie , DSGSD, glissement de terrain, Alpes, Aléa, RGF

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Anisotropy of magnetic susceptibility – a unique tool for active tectonic studies

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☐ Talk
☒ Poster

Anisotropy of magnetic susceptibility (AMS) is a suitable method for investigating magnetic fabrics (determining magnetic foliation and lineation) that may reveal active fault kinematics. However, proper sampling is crucial for obtaining valid information on the deformation within the fault core or in the affected rock or sediment in its vicinity. While the internal deformation caused by sampling does not usually occur in hard rocks, the young sediments are usually more vulnerable to a superimposed artificial deformation. Therefore, the sampling of such material should be done as carefully as possible due to the vulnerability of natural fabric to be overprinted by a plastic box pushing induced fabric during sampling. Such fabrics can be easily recognized by taking controlling boxes from different directions (ideally perpendicular). The resulting fabrics induced by sampling overlaps perfectly with each other in the specimen coordinate system. However, they significantly differ in a geographic coordinate system. There are several ways of AMS sampling to avoid such an origination of the artificial magnetic fabric.

The most efficient way is to take samples perpendicular to the fault plane when investigating a fault´s lineation, which is not mesoscopically visible. However, natural AMS fabrics need not have a straightforward geometrical relationship to the fault plane. In such a case, controlling samples from different directions should be done. If the resulting fabric is affected by sampling, then all the results should be considered as non-valid, and a more careful re-sampling should be done. For such a re-sampling, cubes with oriented face-side fitting inside the plastic box can be excavated by knife first and then cut from the outcrop and placed to the sampling plastic box so the artificial magnetic fabric induced by pushing will be prevented. In addition, sediment can be previously moistened to maintain its cohesion (especially in the case of sand). Another option (ideal for consistent silts and clays, where cohesion is strong enough) is to cut an oriented sample with wider dimensions (e.g., a prism with dimensions 2 x 2 x 10 cm), which can be cut into more cubes that fit into the AMS kappa-bridge (i.e., 2 x 2 x 2 cm per piece).

Proper and careful sampling allowed uncovering extraordinary results from very young faults in Czechia. The recognized strike-slip kinematics in magnetic fabrics from Brno does not fit any known stress field recorded by other faults in the region. Thus, our findings may provide another piece of the puzzle to decipher quaternary active tectonic history in Central Europe.

Keywords: anisotropy of magnetic susceptibility, magnetic fabrics, sampling, active tectonics, faulting

Workshop "Active Tectonics & Dating"

Insights into the propagation direction of slip events based on contemporaneous faulting and bed-parallel slip

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☐ Talk
☒ Poster

The lack of an unambiguous method for determining the propagation direction of slip events on faults over significant time periods limits our understanding of the long-term stability of fault slip propagation directions. A geological means for determining the propagation direction of slip events during the growth of faults is provided by mutually cross-cutting faults and bed-parallel slip surfaces in the Ptolemais Basin, northern Greece.
In the Kardia lignite mine, Ptolemais Basin, bed-parallel slip surfaces intermittently offset the Quaternary faults as they grew to form discontinuities on otherwise continuous fault surfaces. Subsequent fault slip increments bypassed these discontinuities to re-establish a continuous fault trace and leave an associated 'dead' splay. The geometry and displacement distributions at these fault/bed-parallel slip intersections record the fault displacement at the time of bed-parallel slip and whether the next fault slip increment had an upwards or downwards component to its local propagation vector. A database (N = 88) of slip propagation directions and fault throws was derived from continuous mapping of mine faces during lignite extraction over an eight-year period. The data demonstrate a clear relationship between slip propagation direction and the accumulation of fault displacement on individual faults. During the early stages of fault growth, slip events propagated almost exclusively upwards through the mined sequence, but later stages of growth are marked by slip events showing both upward and downward components of propagation. The data therefore demonstrate that the location of the point of initiation of fault slip events on these Quaternary faults varied over the fault surfaces as the faults grew.
The emergence of systematic results from our analyses suggests that cross-cutting relationships between other synchronously active structures (e.g., conjugate faults) can provide a robust means for determining the propagation directions of slip events on ancient faults at outcrop.

Keywords: Normal faults, Fault growth, Slip events, Slip propagation direction, Ptolemais Basin.

Workshop "Active Tectonics & Dating"

Uncertainties on active fault parameters for probabilistic seismic hazard assessment in Provence, France

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☐ Talk
☒ Poster

The quantification of uncertainties is crucial to correctly assess a seismic hazard for safety purposes. Among other sources of uncertainties, the ones associated with the seismic sources are still considerable and are likely to remain high for many more years. Indeed, French instrumental and historical catalog durations are short compared to the return period of significant earthquakes and progress in resolving the French fault activity is limited due to low seismicity and deformation rates, , as well as challenging dating of fault offsets and paleoearthquakes.

We present a site-specific probabilistic seismic hazard assessment (PSHA) study focused on southeastern France, where debates are still open with divergent opinions and where strong efforts are devoted to the characterization of faults and seismic activity. We explore the variability of the computed hazard curves at different frequencies interesting industrials, in order to depict the current diversity of seismotectonic source models and fault models. We use the FCAT-17 catalog (*Manchuel et al., 2018*), which incorporates the instrumental catalog SiHex (*Cara et al., 2015*) and the historical catalog SisFrance (*Scotti et al., 2004*) converted in Mw. We compare several source zone models to take into account different interpretations existing among specialists and we investigate extreme plausible fault models based on information given in the French potentially active fault database (BDFA, *Jomard et al., 2017*) in the Provence region.

PSHA computation is performed using OpenQuake and implemented assuming three main source hypotheses: (1) seismotectonic models with diffuse seismicity, (2) faulting with characteristic earthquakes and (3) faulting with seismicity following a Gutenberg-Richter law. Logic trees enable to take into account epistemic uncertainties on input source parameters and on suitable GMPEs for the French context. Sensitivity tests show that uncertainties on the fault parameters are the dominant factor controlling the variability of the seismic hazard level at various time scales, greater than epistemic uncertainties due to GMPEs and seismotectonic zone models. Finally, this study opens discussions towards alternative models of seismicity generation in intra-continental regions)

Keywords: Active faults, seismic hazard, uncertainty, earthquakes, Provence

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Workshop "Active Tectonics & Dating"

Geomorphological evidence of the neotectonic activity of Mariánské Lázně Fault (Czech Republic) and its influence to local stream network

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☐ Talk
☒ Poster

The Mariánské Lázně Fault (MLF) is a prominent tectonic structure with length of 150 km and prevailing orientation of NNW-SSE, which was active already in the late-Variscan times. Its recent tectonic activity, especially in the NW part, is well known and proved (earthquake foci, mantle-derived CO_2 emanations, geophysical and paleoseismological research). It seems that other parts of MLF (especially of NNW-SSE and N-S orientation) could be also active (or reactivated) during Pleistocene and Holocene. However, the neotectonic activity in the central and southern part is still poorly understood. This study provides a robust set of geomorphological analyses based on Lidar Digital Elevation Models (mountain front sinuosity, basin asymmetry, stream longitudinal profiles, SL index) which could be processed within such a long structure and be used for evaluation of neotectonic activity. All of the analyses showed similar results - NW part, central part and very southern part of MLF, are probably the places with the youngest tectonic activity along the MLF. Also, it seems that central part of MLF has been probably bulged more than the other parts during uplift. The results lead not only to evaluation of tectonic activity and comparison with the active NW part; but also to the localization of those active fault sections as interesting sites for subsequent research and for the evaluation of possible future seismic hazards.

Mentioned results, together with the general morphology and occurrence of fluvial deposits of various ages, have led us to a hypothesis that the different timing of tectonic activity along particular MLF parts affected the evolution of stream network of Mže River and tributaries. The multiple cases of stream captures, changes of stream catchment geometry and tectonically induced occurrence of the Pliocene-Pleistocene fluvial depocenters can be located here. Therefore, we suggest a theory of Pliocene-Pleistocene evolution of local stream network.

The first ideas about evolution of terrain morphology and stream network is proposed by this study, however the subsequent field research is essential (geophysics, paleoseismology) to prove and date the tectonic activity. With those future results, complemented by dated tectonic activity in the northern part of the MLF, we can decipher the complex tectonosedimentary evolution along the MLF during the Pliocene and Pleistocene.

Keywords: neotectonics, SL index, basin asymmetry, mountain front sinuosity, longitudinal stream profiles, stream network

Workshop "Active Tectonics & Dating"

Magnitude 9 along the Himalayan arc during the medieval period ?

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☐ Talk
☒ Poster

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

Keywords : Palaoseismology, Earthquake catalog, Himalaya, Lake sediment

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Archeoseismology and historical earthquakes in SW Poland

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☐ Talk
☒ Poster

The completeness and reliability of earthquake catalogs are fundamental for any seismic hazard assessment. However, usually flawless and precise for the last several years of instrumental data, always in doubt when dealing with historical events. This is particularly true for intraplate regions, such as SW Poland, due to the low deformation rate and associated low to moderate seismicity with a generally long recurrence period. This results in the lack of detailed historical data and significant gaps in the records that might underestimate the seismogenic potential of these regions and/or particular faults. In contrast, numerous worldwide examples prove the occurrence of large and devastating earthquakes in such stable continental settings.

Lower Silesian Block in the SW Poland is separated into Sudetic and Fore-Sudetic Blocks by the 200-km long Sudetic Marginal Fault (SMF), i.e., one of the most prominent tectonic zones in central Europe that exhibits the pronounced morphotectonic escarpment of the Sudetic Mountains front. Its Quaternary activity with a prehistoric earthquake of minimum moment magnitude M 6.3 and the inferred slip rate of about 0.03 mm/year have been corroborated. Several historical earthquakes since the XV century have been reported in the areas adjacent to this fault. However, apart from some damage information, their actual source and relation with the SMF or associated structures have not been confirmed nor studied in detail.

We propose a comprehensive archeoseismological study of churches, castles, and other historical buildings in Lower Silesian Block on both sides of the SMF, especially in the area of c. 2 000 km^2, limited by Strzelin, Grodków, Nysa, Paczków, Kłodzko, and Dzierżoniów. This area was selected due to the preliminary reconnaissance studies, ancient buildings having unusual buttresses, reports of potential damage, unusual architecture, and archive data. Numerous damage features, reconstruction phases, and unusual buttresses observed in selected buildings in Nysa, Ząbkowice Śląskie, Strzelin, Ziębice, and other places with different ages of these events suggest that this area might have experienced at least a few damaging earthquakes since medieval times. The results of this study should fill the gaps in the historical records, allow re-evaluation of the intensity of these events, and provide insights into the potential seismogenic source of these events.

Keyword

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Stabilized accretion wedges - post-thrust processes: A case study of (sub)recent tectonics from the Mikulov region, Outer Western Carpathians

Melichar, R.[1], Baroň, I.[2], Hartvich, F.[2], Rowberry, M.[2], Scholz, D.[3], Bosák, P.[4], Žák, K.[4], Šutjak, M.[1], Rajnoch, A.[1], Černý, J.[4], Kolařík, J.[5]

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☐ Talk
☒ Poster

Thrust belts, and in particular accretion wedges, are usually studied in terms of their thrust structure and past evolution during their culminating orogenesis, which has greatly advanced their understanding. However, young post-thrust tectonics is often neglected due to significantly less influence on the geometry of the structure of accretion wedges, poor exposure of fractures due to their small number, non-penetrativeness, and easy weathering of flysch sediments.

The external flysch belt of the Alpine-Himalayan Zone in central Europe is an excellent example of an accretion wedge. The earthquake distribution shows that the Alps form an active boundary between the European and Adriatic plates, while the West Carpathians are already out of the zone of major tectonic movements since Pliocene and their evolution is finished in terms of thrust tectonics. In this case, the subsequent Pliocene to recent tectonic activity can thus be considered as post-thrust tectonics.

In addition, the tectonic movement of the thrusted allochthonous sheets was oblique here, so that the individual stages of tectonic strain can be better distinguished from each other than in the zones of perpendicular convergence, due to the non-coaxiality of the originated structures. One of the areas where the young tectonic activities of stabilized accretion wedge with oblique thrust direction can be well observed is the Mikulov region (Pavlov Hills, SE Czech Republic).

The Mikulov region is characterized by the presence of the Jurassic limestone fragments incorporated into the Carpathian flysch nappes. Thrust tectonics is well researched here. Competent layers of Jurassic limestones comprise ramps and fault-bent folds. Post-thrust tectonics is characterized by younger faults. Based on a detailed geomorphological analysis of 1-m resolution DTM (LIDAR 5G), the location of the Mikulov fault was specified quite precisely. Aerial photographs from different periods of the year made it possible to characterize the accompanying structures, which were verified by field structural data.

Completely extraordinary information was found in caves created in Jurassic limestones. The Cave “Na Turoldu” provided speleotectonic markers of young displacements along regional strike-slip faults and fractures, such as tilting of the entire cave passages with soda-straw speleothems or speleothem damage by reactivated faults. The speleothems of the “Na Turoldu” Cave provided good material for speleoseismological research and constrained the (sub)recent age of the considered movements.

Keywords: post-thrust faulting, accretion wedge, neotectonics, West Carpathians, geomorphology, caves

Workshop "Active Tectonics & Dating"

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

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☐ Talk
☒ Poster

Southern California accommodates a substantial proportion of the Pacific-North America plate motion, partitioned within a regional network of active faults, including the San Andreas Fault (SAF). Segmentation and slip partitioning among the different segments lead to complex regional seismic activity in terms of both magnitudes, frequency, and seismic cycle as the plate-boundary fault system is not limited to the sole SAF. East of San Gorgonio Pass, the segmentation of the SAF is particularly puzzling with an enduring debate about the identification of the main strand of the SAF, the segment that would transfer deformation to the Los Angeles basin. Here, we investigate one of these strike-slip faults, the Banning Fault (BF), located in the Coachella Valley, contributing to establish a long-term slip-rate to enhance our understanding of the slip partitioning. Morphological mapping of the alluvial fan sequences, using high-resolution remotely sensed data from the B4 LiDAR project, facilitates the measurement of a mean right-lateral offset of 342 ± 56 m of the most prominent surface observed at the study site. To constrain the rate, numerous quartz-rich samples, collected from both surfaces and depth profiles on the alluvial surfaces, were processed for ^{10}Be and ^{26}Al Cosmogenic Radionuclide (CRN) isotope dating. The CRN data help to constrain the ages of 5 different levels of the local bajada, T1' (14.2 ± 1 ka), T2 (30.2 ± 2.1 ka), T2' (33.2 ± 3 ka), T3 (59.1 ± 8.2 ka) and T4 (94.6 ± 8.8 ka), extending the dataset of cosmogenic radionuclide model ages in the region. These model ages are used to estimate a long-term slip rate of 13.2 ± 2.5 mm/yr on the Banning Fault over the last 33 ka, adding an important constraint on the long-term slip rate of the southern SAF system. This new slip-rate implies that the Banning Fault has the potential to propagate ruptures across the San Gorgonio restraining bend, which is likely a more plausible path than the Mission Creek Fault to the north. Finally, this new BF rate should help revising the numerous deformation and kinematic models focusing on Southern California over a longer time period by first and foremost updating the late-Holocene BF rate of 4 mm/yr used in the current models, which underestimate this major fault strand in the complex slip-partitioned San Andreas fault system.

Keywords: Southern California, Slip-rate, CRN dating

Workshop "Active Tectonics & Dating"

Radiocarbon Dating of the 1934AD Bihar-Nepal Earthquake Surface Rupture Reveals Systematic Biases that Cause Artificially Aging of Historical events

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☐ Talk
☒ Poster

Because paleo-earthquakes dates are derived mostly from detrital charcoal radiocarbon ages, the dates associated with paleo-ruptures are expected to be older than the great earthquakes described in historical chronicles. This is because, in general, radiocarbon dates must be older than the actual charcoal deposition ages by the age of the wood at the time of burning and a transport time, including possible reworking processes. Commonly, the wood is already decades old or more when burnt by fire. After an initial period in situ, the charcoal is transported, then deposited after eventually suffering multiple reworking. Along the Main Himalayan Thrust faults, the period following great earthquakes is typically prone to enhanced sediment transport and reworking, given the large volumes of seismically-triggered landslides and the enhanced transport capacity of the rivers during the summer monsoon periods that follow the event. The « old-wood effect » that results from these processes, which may include both inbuilt age and transportation time-lag, is well known but rarely quantified, mostly because of the limited sets of detrital charcoals sampled at most paleo-seismic sites, due to charcoal availability or budget restrictions. Most of the time, the related age bias is ignored. Yet, its existence necessarily introduces further bias on the best Bayesian event ages, and always in the same direction, namely that which artificially ages the timing of historical events. Here we document such a systematic bias by using more than 50 radiocarbon-dated charcoals sampled in the Sir and Charnath Khola valleys, two emblematic sites in Central-eastern Nepal, at the western end of the 1934AD mesoseismal area and surface rupture. The large number of samples is critical to demonstrate that detrital charcoals deposited in sediments capping the fault scarp slightly predate the earthquake, by a time lag that corresponds to the inbuilt age and transport time.

Keywords : Active faults, paleoseismology, Radiocarbon dating, inbuilt ages

Rizza, M., L. Bollinger, SN. Sapkota, P. Tapponnier, Y. Klinger, C. Karakaş, E. Kali, M. Etchebes, D.R. Tiwari, I. Siwakoti, A. Bitri, S. Bes de Berc (2019) Post-earthquake aggradation processes to hide surface ruptures in thrust systems: The M8.3, 1934, Bihar-Nepal earthquake ruptures at Charnath Khola (Eastern Nepal), *Jour. Geophys. Res.* , https://doi.org/10.1029/2018JB016376

Workshop "Active Tectonics & Dating"

Neotectonic evolution of the Northern Calcareous Alps determined through fault-slip analysis, radiometric dating of cave deposits, and morphology of deep karst systems

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☐ Talk

☒ Poster

Tectonics and morphology of the Northern Calcareous Alps (NCA) have been determined by lateral extrusion since the late Oligocene. The major crustal-scale strike-slip faults are still active. Yet, their modern activity is mainly manifested by earthquakes (up to M6) with scant evidence in the geological record. Tectonic research focused on Salzach-Ennstal-Mariazeller-Puchberger (SEMP), Inntal, and Mur-Mürz faults, as well as the eastern boundaries of the Alps. Lesser attention has been paid to the western part, Salzburg Alps, that is cut by the 110 km long fault system Königssee–Lammertal–Traunsee (KLT). Together with Inntal, Mur-Mürz and SEMP faults, KLT is considered the main structure that bound the escaping wedges during Oligocene-Miocene lateral extrusion. All those faults are seismogenic and yet KLT has not been studied in terms of Plio-Quaternary tectonics. Since the KLT bounds karstic plateaus with a deep karst system, it is highly plausible that the evolution of these caves is linked to its neotectonic activity. The great advantage of caves is their potential in protecting structures from erosion. Dating sediments from deep caves directly connected to faults is a perfect opportunity to study both, neotectonics and landscape evolution from a different perspective. The Salzburg Alps is one of "the richest" caves regions in the world and yet the robust chronology of the uplift rate variations is still not obtained.

Here I present preliminary results of project that pursued a multimethod approach combining tectonic research in various scales with complex geochronological analysis. Fault-slip data, including cave passage offsets that prove fault motion after cave development, are used to reconstruct the paleostress fields. To unravel the relative massife movement a morphometric analysis is implemented in order to reconstruct subsequent paleo-base-levels in individual massifs.

Crucial to recontruct NCA evolution is to understand the timing of tectonic processes, including possibly co-seismic fault rejuvenation events as well as long-term incision/uplift rate. Speleothems damaged due to the offset of a cave passage were sampled to date pre- and post-faulting speleothems which allows bracketing the displacement event. The long-term incision rate will be estimated via the burial age of cave clastics that were deposited in the phreatic conditions and now are perched in paleophreatic passages above the modern valley floor. This will be constrained with paired (^{10}Be and ^{26}Al) of cosmogenic nuclides, and if the burial age exceeds 5 Ma, with three isotopes (^{10}Be, ^{26}Al, ^{21}Ne) to extend the studying time frame up to 10 Ma. So far such a multimethod approach has not been pursued nor in the Alps nor elsewhere. Data were collected in Hoher Göll, Hagengebirge, Tennengebirge and Leoganger Steinberge massifs.

Keywords : paleoseismology, cave, topographic uplift, U-series dating, cosmogenic nuclides, Alps

Workshop "Active Tectonics & Dating"

Need for better fault-offset dating for understanding the inconsistencies between the seismicity rate and the predictions of the fault models in south-eastern France

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☐ Talk
☒ Poster

Active faults in intraplate settings, exhibiting slow deformation, rarely expose clear morphotectonic expressions. In many cases, their characterization relies only on rare neotectonics slip rates, often integrated over the Holocene, Quaternary or Plio- Quaternary. In addition, the strain accumulated along these tectonic structures and therefore their locking depth and associated slip deficit usually remains out of reach of geodetic measurements.

Finally, the micro-seismicity located in the vicinity of most of these structures usually fails in delineating clear active fault segments geometry. The seismogenic potential therefore remains tainted with large uncertainties. It is one of the main reasons why very little attention has been paid to testing how French seismicity compares to the predictions of tectonic models. In this work, focused on South-Eastern France, we confront the potentially active faults database of the French metropolitan territory with a recently published catalog of historical and instrumental seismicity. Seismicity rates are corrected for completeness biases and are then compared to the predictions of several endmember tectonic models. The rates of earthquakes predicted by the tectonic models appear six to eighteen times higher than the historical and instrumental observations.

Such a difference could be explained by an overestimation of the seismogenic potential of the faults or by different average seismicity rates at historical and longer-term timescales. This variation, if genuine, could be implied by spatiotemporally clustered seismicity due to tectonic or non-tectonic modulations suggesting non-poissonian behavior of the largest earthquakes.

Better fault-offset dating can make the difference between the alternative interpretations.

Keywords : Active faults, paleoseismology, Radiocarbon dating, inbuilt ages

Vallage, A., & Bollinger, L. (2020). Testing fault models in intraplate settings: a potential for challenging the seismic hazard assessment inputs and hypothesis?. Pure and Applied Geophysics, 177(5), 1879-1889.

Workshop "Active Tectonics & Dating"

RESIF-FACT round table

Hybrid format (Praz-sur-Arly, France - Belambra Club “L’Alisier” & online) September 14 – 16, 2021

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

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The 11-11-2019 Le Teil earthquake (Mw4.9), located in the Rhône river valley occurred along the La Rouvière fault (LRF) within the NE termination of the Cévennes faults system (CFS). This very shallow moderate magnitude and reverse-faulting event inverted an Oligocene normal fault which was not assessed to be potentially active, causing surface rupture and strong ground shaking. Its morphology shows no evidence of cumulative reverse faulting during the Quaternary. These observations lead to the question whether the fault was reactivated for the first time since the Oligocene during the Teil earthquake, or if it had broken the surface before, during the Quaternary period, but could not be detected.

To answer these questions, we launched paleoseismic investigations along the LRF to analyze and characterize evidences of paleo-ruptures in Quaternary deposits. 11 trenches were dug along the section that broke in 2019. Five trenches yielded favorable Quaternary deposits (slope colluvium and eolian deposits) lying against the ancient LRF normal fault mirror carved in the Barremian limestones to document past-coseismic deformations. The radiocarbon and OSL dates (from “bulks” collected into colluvium clayey-silty matrices) within 2 trenches, LR1 and LR4, located in the central and southern parts of the LRF, respectively, suggest that at least one event prior 2019, and maybe, more occurred in the past 17 Ka. The radiocarbon dates within trench LR6, located in the northern part of the 2019 rupture suggests that a penultimate event occurred between the end of the 15th century and the beginning of the 17th century with kinematic characteristics similar to the 2019 event (sense of movement, amount of displacement). The fact that these events are not preserved in the morphology is explained by the small amount of displacement and a long return period, consistent with the low strain rate measured by GPS in this region ($0.5 – 1.0 \times 10^{-9}$ yr^{-1}). Our study shows that it is therefore fundamental to carry out more detailed paleoseismological investigations in metropolitan France, especially along ancient faults favorably oriented with respect to the present stress field. Those are already planned in the next coming months along other segments of the CFS.

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Workshop "Active Tectonics & Dating"

FACT in Northern Alps: Questions and approaches

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☒ Talk
☐ Poster

The Alpine region is one of the most seismically active areas in France (Drouet et al., 2020). If the actual horizontal velocity deduced from GPS is very low in the western Alps (Nocquet et al., 2016), the exhumation of about 2 mm/yr in the study area points out the active tectonic context (Sternai et al., 2019). For example, the Belledonne Massif is today affected by recurrent active but deep deformation, demonstrated by historical seismicity (Wilhelm et al., 2016), instrumental data (Thouvenot et al., 2003) and geodetic data (Walpersdorf et al., 2015). However, as elsewhere in the Alps, most of the seismicity is a background seismic activity highlighted by local and recurrent swarms. Compared to others swarms in the French Alps, the Maurienne unprecedented swarm (Gueguen et al., 2021) is similar to Vallorcine swarm (Cara et al., 2017) and to the Ubaye swarm (De Barros et al., 2019) in terms of tectonic and geological position: somehow linked with the reactivated Hercynian and/or Alpine structures and triggered in the crystalline basement. In parallel, in terms of tectonic geomorphology in the the Alps, kilometers scale recent scarps with normal motion are linked with gravitational movement and identified as gravitational sackungs (Hippolyte et al., 2006, Le Roux et al., 2009). They must be triggered by a debuttressing process controlled by glacial retreat and gravity but are distinct from “real” active tectonic features. Anyhow, in order to discuss the tectonic activity, the slip rates have to be quantified and few dating studies have been carried out to estimate those in the northern Alps yet. In both cases of geomorphic evidences or seismic evidences of active faulting in our region, the same major key issue remain to be addressed by both scientists and local authorities for risk management: What fault is activated, re activated? What may be the maximum magnitude on these structures? What may be the expected consequences on infrastructures in case of localized surface ruptures? What is the best dating methods to apply? Are paeloseismic studies worth for such post glacial features? These questions also arise in post-L’Aquila or Le Teil contexts where seismic hazard assessment in slow deforming regions is demonstrated to be a new challenge.

Keywords : swarms and scarps, active faults, alps, seismic hazards

Workshop "Active Tectonics & Dating"

The potentially active Marche fault in NW Massif Central : preliminary field observations, topography and drainage characteristics (Region 6 working group of the FACT axis - ATS-Resif)

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☐ Talk
☒ Poster

In the framework of the « Failles ACTives » (FACT) axis of the Action Transverse Sismicité of the consortium RESIF (https://www.resif.fr/actions/action-transverse-sismicite/), the R6 region is devoted to the study of potential actives faults in central France (Bassin de Paris and its surroundings). Among interesting targets, the Marche fault, in the NW corner of Massif Central, is probably inherited from the Variscan (upper Palaeozoic) orogeny. Its present morphology is that of a ≈ 100 km-long, roughly E-W trending scarp. In its eastern two thirds, from the village of Colondannes to the Montluçon Basin, it appears on average resolution (25-30 m) DEMs as a rather sharp, continuous feature. This, combined with low-to-moderate seismicity has led to classify it as a potentially active fault.

On higher resolution (5 m) DEMs, and in the field however, the fault has a more subdued, discontinuous morphology, with scarp slopes mostly gentler than 10°. Some rivers crossing the fault exhibit knickpoints in their longitudinal profile, but these are upstream from the fault, while the river bed itself is not clearly vertically offset by the fault. Besides, the local landscape is clearly marked by human activity, mostly agriculture, centuries of which may have obscured any sign of tectonic activity.

The Marche fault thus bears little evidence of present-day faulting. The key to assessing its level of activity is probably paleoseismology in trenches dug across the fault where it cuts through Quaternary deposits. This requires first to accurately locate the fault trace, by means of surface geophysics, e.g. high-resolution seismic reflection.

Workshop "Active Tectonics & Dating"

Activities of the RESIF-ATS-FACT group for Northern France region R7 to improve the knowledge on potential active faults

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☐ Talk
☒ Poster

Northern France is a moderately active seismotectonic region in which several potential active structures are identified onshore (*e.g.,* along the Artois hills) and offshore (*e.g.,* along Dover Strait). In the framework of the "*Faille Actives*" axis (FACT) of the *Action Transverse Sismicité* (ATS) of the French Consortium Resif, a group of academics from Universities, CNRS Laboratories, Observatories and industrial companies from France and Belgium was created in 2019 to critically assess, update and complete the potentially active fault database (BDFA) compiled by the IRSN (Jomard *et al.*, 2017). The group met twice in mid-October 2019 and 2020, and started to share ideas and informations about published works, datasets, field observations, etc. One of the strength of the group is its interdisciplinarity (geologists, geophysicists, geomorphologists, quaternarists), on land and at sea, and its cross-border partnership.

During 2020 meeting, a small online workshop has been organized to allow participants to present their past and present research works in the Hauts-de-France region (North of France). Presentations concerned not only the shallow geology and landscape analyses but also recent researches about deep basement inherited structures that are potentially involved in the active tectonics processes. Northern France geology is indeed governed primarily by a Meso-Cenozoic sedimentary cover overlying unconformably a deep basement which has been severely deformed (faulted and folded) during the Variscan orogeny and reactivated during the Pyrenean-Alpine orogeny. Understanding the relationship between the ancient basement structures and recent surface structures is an important target to understand and characterize the potential active faults in the region.

In the present contribution, we present synthetic results (field observations, topographic/bathymetric landforms and geophysical results) about seismotectonics and structural investigations across the Strait of Dover, the Artois Hills, the Bray region, the Mélantois area and the Nord - Pas-de-Calais coal basin.

Keywords : Northern France, Seismic Hazard, Active faults,

Workshop "Active Tectonics & Dating"

The Maladeta-Bedous Fault System in the Pyrenees

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☐ Talk
☒ Poster

The Maladeta-Bedous Fault System is a 150 km long structures extending between the Aspe valley in the Atlantic Pyrenees and the Aran valley in Catalonia and accommodating late Miocene to present vertical movements in the high range of the Pyrenees. Individual faults within the system were identified through geomorphological evidence such as the displacement of high-elevation low-relief surfaces, knickpoint and differential incision of valleys and ridges. Their coincidence with the main Pyrenean thrusts led to propose that they correspond to a single system that results from the inversion of major alpine thrusts. The model matches well with the location and kinematics of instrumental seismicity as with the location of some historical earthquakes. The characterization of the Maladeta-Bedous System has benefited from the analysis of digital elevation models with 25 m of resolution combined with field observations. Significant uplift along the axial zone is also attested in Miocene times by paleontological data, low-temperature thermochronological data and by InSAR mapping. These latter results take advantage of the recent advances in mapping vertical motions by the emergence of satellite imaging with Sentinel-1 fleet deployment where no GPS data is available. They resolve mm-scale differential vertical displacement between the High Chain and the Northern Pyrenean Zone located at the level of these faults. The origin of these vertical displacements is still under discussion, but some processes have been suggested as faulting accommodating differential erosional isostatic rebound, removal of lithospheric mantle.

A better characterization of the quaternary activity of the Maladeta-Bedous fault System will require an effort in detecting offsets of more recent landforms and sediments. The analysis of high-resolution LiDAR-derived earth Digital elevation models, progressively available in the Pyrenees, is regarded as a promising tool to locate young sediments along the trace of the fault system, allowing for trenching analysis and the identification of fault bedrock scarps suitable for exposure dating. Additionally, the study of the lacustrine record preserved in the neighboring lakes could contribute to understand the recurrence of moderate-large earthquakes in the area.

Keywords : Pyrenees, Active faulting, neotectonic, Maladeta-Bedous Fault System

Workshop "Active Tectonics & Dating"

Active tectonic in the SE France (region n°3) in the framework of the FACT axis (RESIF)

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Géoazur Université Côte d'Azur-CNRS, France

☐ Talk
☒ Poster

Within the framework of the "Failles ACTives" axis (FACT) of the Action Transverse Sismicité of the consortium RESIF, the Region 3 working group (Geoazur, IsTerre, IRSN) is in charge of studying and characterizing the active structures in the area of the Southwestern Alps, the Ligurian Sea and Corsica.

Priority has been given to the investigation of submarine escarpments identified as being related to the Ligurian fault system at the origin of major historical earthquakes such as that of 23 February 1887. We performed a dive using the Hybrid-ROV Ariane (Ifremer) operated from the R/V L'Europe, during the scientific cruise TELEPRESENCE (PIs: O. Soubigou and F. Leclerc) along the Marcel fault scarp, belonging to the western part of the Ligurian faults system. The HROV dive lasted 3h at a mean depth of 2280 m b.s.l., and was recorded by two cameras. It proceeded at 1.5-2 m above the seafloor and zigzagging across the fault scarp. Overall, the seafloor is covered by hemipelagic sediments. The target scarp is hardly visible but revealed by a 15-20 m bathymetric smooth change recorded by the HROV. However, we did not identify any morphology of tectonic origin along this scarp. The only noticeable features are submetric form, probably of biologic origin. Ce travail confirme la difficulté des analyses de la tectonique active en mer et en particulier le problème du passage de l'échelle des données géophysiques à celle du terrain. We have planned a new diving campaign in november 2021 off the coast of Imperia on the eastern part of the Ligurian faults system where deformation trhough quaternary deposits seems is better expressed.

Other targets are also being worked on: (i) in the lower Var valley, northeast of Nice, with the reanalysis of Pleistocene terraces and fractures associated with the Donareo fault as well as (ii) recent structures in the Ubaye and Stura valleys that could be related to the Barcelonnette seismicity swarms.

Workshop "Active Tectonics & Dating"

Perspectives in studying active faults in metropolitan France: looking for markers of activity of major inherited structures in the Armorican Massif (R8 FACT region)

Clément Perrin[1], Julie Perrot[2] and the members of the R8 FACT region

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☐ Talk
☒ Poster

The northwestern part of France is characterized by a various set of major faults and shear zones, mostly inherited from past Protero-Paleozoic orogens (Cadomian, Variscan), and extensional (Meso-Cenozoic) and compressional (Cenozoic) events. Currently the region is located far from plate tectonic boundaries and is submitted to very low strain rates. Still, a fairly high activity of moderate size instrumental earthquakes (M~3-4) has been recorded in the region, which has also experienced several large historical earthquakes in the past. Among them, the large M6 1799 Vendée earthquake has been recently revisited by recent studies, raising the question of the potential activity of the Machecoul fault as a source of the earthquake.
Kaub et al., (2021) carried out a multidisciplinary study in the epicentral region, onshore and offshore, and better characterized the lateral segmentation of the Machecoul fault, basins geometry and sediment infilling in the Baie of Bourgneuf, and inferred the Neogene and Quaternary sediment thickness. The offshore Plio-Quaternary units infill paleovalleys and seem to increase in thickness westward. The deposition of these units appears to be controlled by the southern escarpment of the Machecoul Fault. The planar contact between the Plio-Quaternary sediments and the basement along the fault trace as well as the thickening of these sedimentary units near this contact suggests tectonic control rather than erosion. Onshore, the Machecoul fault trace is tenuous and gradually fading out eastwards. Even if the new observations suggest a recent activity of the Machecoul fault bounding the basin to the North, a Holocene activity cannot be firmly demonstrated. Upcoming studies, involving subsurface geophysics, neotectonics and paleo-seismological survey will be performed to eventually demonstrate the relation between the fault and the earthquake.

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Workshop "Active Tectonics & Dating"

Morphotectonics (high resolution / LIDAR) and paleoseismology of the Trevaresse Fault (FACT axis Region 2 working group)

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☐ Talk
☒ Poster

This research project is part of the "Active faults - France" (FACT) action carried out by the RESIF consortium, one of whose objectives is to better understand seismotectonics and processes that control active deformation and seismic hazard in metropolitan France. In addition, the FACT action also aims to improve the temporal resolution of past earthquakes by developing paleoseismological investigations (trenches in Quaternary deposits), involving also sub-surface geophysical methods to locate potentially active structures under Quaternary sedimentary deposits. Within the framework of the RESIF consortium, we wish to re-launch work in Provence, which is one of the target areas of the FACT action and for which CEREGE is the regional coordinator (region 2).

One of the proposed axes of our research project is to continue morphotectonic analyses in Provence by using new tools of very high resolution topography such as LiDAR imagery or SfM photogrammetry by drone. We first focus on the Trévaresse fault, whose historical reactivation was responsible for the Lambesc earthquake in 1909, one of the most destructive shaking in recent history in France, with strong damage to the villages. One of the advantages of this study area is that the morphology, surface rupture and fault segmentation associated with the activity of the geological structures have been partly evidenced by studies in the 2000s (Chardon & Bellier., 2003). Moreover, the surface rupture of the 1909 earthquake was identified in an open trench (Chardon et al., 2005) and the quaternary sediments excavated there were affected by multiple earthquakes. However, none of the formations in this trench have been dated and we therefore have no knowledge of the return times on this fault system.

Our objective is to refine first the mapping of quaternary morphological surfaces and tectonic scarps. In 2021, our work focused on the morphological expression of active fault segments and geomorphological anomalies identified by exploiting high-resolution (1 meter) topography surveyed with airborne LiDAR by a team from the University of Caen (Thomas, 2018). These data have been complemented by field observations and new structural geology data and some geophysical surveys. In addition, photogrammetric surveys by drones were performed to complete very high-resolution topographic data (<10cm/pixel). In the near future (2022), we would like to open 1 to 2 paleoseismic trenches to confirm or not the presence of surface ruptures on other fault segments of the Trevaresse linked to the past occurrence of major earthquakes. If the potential sites seem too limited, we will reopen a trench in the area already excavated by Chardon et al. (2005) to date the affected deposits and eventually document more evidence of past earthquakes.

Finally, this work aims at dating Quaternary morphological markers and paleoseismic events identified in the trenches. This step will be carried out by means of appropriate dating methods in the sedimentological context of the alluvial terraces of the Durance, by using the cosmogenic isotope technique (36Cl), and optical luminescence (OSL), these two methods being widely used at CEREGE.

Keywords : Active faults, Provence, LiDAR, paleoseismology