COLLOQUE

JURA TECTONICS 2024 CONFERENCE

ABSTRACT BOOK

De l'évolution tectonique passée aux projets appliqués au sous-sol

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Besançon (France)
9-11 octobre 2024

Maison des Sciences de l'Homme
et de l'Environnement
1 rue Charles Nodier

https://juratectonics.sciencesconf.org/

Wednesday 9th October 2024

13:30 – 14:00 ▪ Welcome of participants

14:00 – 14:15 ▪ Welcome speech

Session 1. Tectonic evolution of Jura: insigths from multidisciplinary approach

Chairperson: ***Flavien Choulet***

14:15 – 15:00 ▪ **Peter Jordan** – **Keynote.** Hans Peter Laubscher and the Jura fold-and-thrust belt [KN1]

15:00 – 15:25 ▪ **Jon Mosar** – On basement tectonics and décollement in the Jura Mountains

15:25 – 15:50 ▪ **Bertrand Maillot** – Mecanical modelling and tectonic style

15:50 – 16:20 ▪ Coffee break

16:20 – 16:45 ▪ **Raphael Schneeberger** – Evolution of the eastern tip of the Jura Fold-and-Thrust Belt: insights from recent 3D reflection seismic and borehole data

16:45 – 17:10 ▪ **Luca Smeraglia** – Timing of deformation and past fluid flow in the Jura Mountains

17:10 – 17:35 ▪ **Catherine Homberg** – Stress though time and space: insights from the Jura Mountains and surroundings

19:30 ▪ Repas de gala au restaurant « Péniche Le Chaland ».

Thursday 10th October 2024

8:00 – 08:30 ▪ Welcome of participants

Session 2. Tectonics and applied geology

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*Chairperson: **Julie Albaric***

8:30 – 9:15 ▪ **Pierre-Yves Jeannin** – **Keynote.** Applied geology and enginerring projects in the Jura mountains [KN2]

9:15 – 9:40 ▪ **Victor Klaba** – Hydrostructural approach for a better comprehension of karstic hydrosystem

9:40 – 10:05 ▪ **Benoît Valley** – Current stress field and its importance on geothermal project development in the Jura

10:05 – 10:30 ▪ **Marius Gruber & David Polasek** – Geothermal prospection at the Jura – Molasse Basin transition

10:30 – 10:55 ▪ Coffee break

10:55 – 11:20 ▪ **Christophe Nussbaum** – Fault zone in claystone: the contribution of the Mont Terri Underground Rock Laboratory

11:20 – 11:45 ▪ **Benoît Hauville** – Helium exploration in Avants-Monts (NW Jura), a good opportunity to acquire new data and revisit the structural setting

11:45 – 12:10 ▪ **Laurent Beccaletto** – Late Paleozoic basins: geodynamics and resources in NW Jura

12:10 – 12:35 ▪ **Johannes Pietsch** – Tectonics and Solution Mining: How much of knowledge is needed for a safe operation?

12:35 – 14:00 ▪ Lunch buffet

Session 3. Recente/Active deformation along the arc

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*Chairperson: **Julie Albaric***

14:00– 14:25 ▪ **Julie Albaric *et al.*** – Active deformation in the Jura in the framework of the Western Alpine system

14:25 – 14:50 ▪ **Tobias Diehl** – New insights into present-day seismotectonic processes of the Jura fold-and-thrust belt from recent seismicity

14:50 – 15:15 ▪ **Jérome van der Woerd** – Seismicity, deformation and geomorphic processes in the southern Upper Rhine Graben

15:15 – 15:40 ▪ **Amélie Quiquerez** – How archaeological investigations can help to assess neotectonic activity in the southern Jura ?

15:40 – 16:05 ▪ **Robin Marchant & David Giorgis** – Tectonics of the Alpine foreland: what lies beneath the lakes?

16:05 – 18:00 ▪ Poster session followed by a closure cocktail

18:00 ▪ Free-time dinner in Besançon

Friday 11th October 2024 : Excursion

8:00 ▪ Departure from Besançon

9:00 – 12:00 ▪ **Fuans cross-section**

12:00 – 13:30 ▪ Lunch (Restaurant : Au coeur des faims, Les Fins)

13:30 – 16:30 ▪ **Le Locle A20 bypass**

17:30 ▪ Back in Besançon

Hans Peter Laubscher and the Jura fold-and-thrust belt

Peter Jordan[1]

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Abstract

Various hypotheses on the origin and the geometry of the Jurassic Fold and Thrust Belt that are generally recognised today can be traced back to Hans Peter Laubscher (1924 - 2015), whether it was his own original ideas or the fact that he helped them achieve a breakthrough. Without claiming to be exhaustive and not in chronological order, some of them are highlighted and explained in more detail here.

Firstly, a work-related contribution that applies not only to the Jura Mountains, but especially there.: H.P. Laubscher taught his students to map conceptually. Particularly in areas, where outcrops are rare and often difficult to discover due to the vegetation, it is important to develop a tectonic concept in advance and to search specifically for crucial outcrops where a concept can be verified or falsified.

The Fernschub («long-distance push») concept goes back to August Buxtorf (1877 - 1969), who in turn was able to build on the work of Fritz Mühlberg (1840 - 1915) and others. However, it was H.P. Laubscher who helped the theory achieve a breakthrough by refuting the arguments of the many opponents who continued to exist into the second half of the 20th century. Particularly noteworthy is his elegant and convincing argumentation against various hypotheses of an autochthonous origin of the Jurassic Fold and Thrust Belt.

H.P. Laubscher's comprehensive work on the subject covers a wide range from the rheology of anhydrite to the cause of the Fernschub. Although he initially considered gravitational causes for the latter, with the establishment of plate tectonics he soon moved on to a connection with the overthrusting of the central massifs. H.P. Laubscher postulated an undisturbed basement dipping to the south above which the basal décollement (already postulated by Buxtorf) could develop. And from this basal décollement, the demand for a mass balance in the sheared masses is necessarily derived. Consequently, H.P. Laubscher introduced cross section balancing, originally developed by C.D.A. Dahlstrom and others, in the Jura Fold and Thrust Belt.

After helping large-scale concepts achieve a breakthrough, Laubscher turned his attention to small-scale key locations. The more complex the situation, the more attractive it was to him. In one of his last papers, he compared it to a conundrum, a riddle, whose answer is an unexpected twist. One of his favourite topics was the interaction of the Miocene Jurassic folds running roughly SW-NE with the inherited Eocene to Oligonocene Rhine Rift structures running roughly N-S. He devoted himself meticulously to both tiny areas and the tracing of large structures across the entire Jurassic fold and thrust belt. His interest in the synkinematic reactivation of Palaeozoic (E-W running) basement structures led him to the concept of the «thrust mill», a mechanically and kinematically convincing explanation of out-of-sequence structures in fold-and-hrust belts.

In this talk, selected examples from the work of H.P. Laubscher will be used to shed light on their relationship to knowledge gained since then and to recent hypotheses and concepts.

Applied geology and engineering projects in the Jura mountains

Pierre-Yves Jeannin[1]

[1]Swiss Institute for Speleology and Karst Studies

Abstract

Our knowledge of the underground is completely based on models, which are used to inter/extrapolate observed data. However, for civil engineering and hydrogeology the aim is to know what geological conditions are to be found at a given location, ideally with an uncertainty in the order of ~1m. For structural geologist, the main objective is that models of the Jura folds and faults reproduces structures which are consistent with general tectonic concepts based on rock deformation rules. As a result the way models are constructed are different, even sometimes contradicting.

However, data from applied projects are fundamental for constraining the models, and, conversely, principles from academic models bring keys for interpolating the data. In other words we need each other!

Through applied examples, the talk will suggest how geological are data used in some applied projects. We will also suggest a way how data should be collected and managed in order to improve the building of 3D models in order to improve the situation for both academic and applied point of views. Uncertainty of the models is a key-question which will be discussed as well.

Two examples will be used:

The first one is related to the understanding of the hydrological regime along the Doubs river. 3D models covering ~1500 km^2 were constructed providing an outlook of the groundwater resources as well as the interactions between the Doubs river and groundwater bodies. This example shows how geology is used for karst hydrogeology, but also sometimes how hydrogeological information may help refining geological models.

The second example is related to tunnels, for which geological models are necessary for the planning, designing and digging of this type of infrastructure. In the Jura Mountains the occurrence of karst features (voids, water or sediments) represent a strong source of potential problems. For about 10 years a method was developed for assessing karst in tunnel digging. Through various case-studies, the way geological data are used for these predictions will be presented.

List of posters

Abi-Nader Anthony *et al.* – Hydro-geophysical monitoring in the Jura mountains [P11]

Billau Antonin *et al.* – Insights into Jura fold-and-thrust belt structuration via U-Pb on carbonates [P4]

Brett Alannah C. *et al.* – Investigating sub-seismic fracture networks in the Muschelkalk Group in the Wutach Gorge (Tabular Jura, DE), towards a revised CO2 storage potential assessment in Switzerland [P5]

Caldeira Jefter *et al.* – Multi-scale structural mapping and analysis of natural fractures of Creux-Du-Van -Central Internal Jura) [P6]

Giorgis David *et al.* – Evidence of an active lacustrine subthermal vent in the Lake Geneva [P2]

Goncalves Philippe *et al.* – Eocene to Oligocene tectonic inheritance in the front range of the Jura fold-and-thrust belt (Avant-Monts, Besançon, France) [P12]

Guglielmetti Luca *al.* – Slope-design et calcul statistique dans un massif rocheux plissé, chevauché et fracturé (Carrières des Granges, Le Locle) [P10]

Jacmaire Jean-Charles – Projet tunnelier de la Ligne Directe CFF entre Neuchâtel et La Chaux-de-Fonds [P13]

Klaba Victor *et al.* – Hydrostructural approach for a better comprehension of karstic hydrosystem – Transkarst Project [P3]

Marchant Robin – Tectonique de l'avant-pays alpin : que ce cache-t-il sous les lacs ? [P9]

Marro Adeline *et al.* – Basement faults inheritance in the detached cover of the Jura Fold-and-Thrust Belt: a new kinematic interpretation [P1]

Signer Salomè *et al.* – Systematic 3D geological modelling of the Jura fold-and-thrust belt (Switzerland). Part 2/2: Current state of implementation [P8]

Ursprung Anina *et al.* – Systematic 3D geological modelling of the Jura fold-and-thrust belt (Switzerland). Part 1/2: Aims and methodology [P7]

Basement faults inheritance in the detached cover of the Jura Fold-and-Thrust Belt : a new kinematic interpretation

Adeline Marro[1], Sandra Borderie[1], Louis Hauvette[2], Matteo Basilici[1], Jon Mosar[1]

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Abstract

Since the early Miocene, the sedimentary cover of the Northern Alpine Foreland has been detached from its basement and displaced approximately 30 km towards the northwest in a thin-skinned style deformation, leading to the formation of the Jura Fold-and-Thrust Belt (FTB). The influence of the basement's topography and its pre-existing structures on the structural geology of the Jura FTB has been well-discussed. Analog models have shown that the activation of a normal fault in the basement can create decoupled structures in the sedimentary cover that overlie a viscous layer (Withjack & Callaway, 2000; Schori et al., 2021). During a later compression phase, these faults in the sedimentary cover are passively displaced above newly formed thrust faults (Schori et al., 2021).

In a regional context, major geodynamic events such as the opening of the Alpine Tethys, the flexure of the lithosphere, and the development of the European Cenozoic Rift System could have formed or reactivated normal basement faults, inducing normal and reverse faults in the sedimentary cover of the Northern Alpine Foreland. These latter structures have been passively displaced and may now be preserved in the present-day Jura FTB. The objective of this study is to identify these inherited faults in the western part of the Jura FTB. The Crêt de la Neige summit, located north of the city of Geneva, is one of the best areas within the internal part of the belt to observe these inherited structures.

2D kinematic forward modeling, fold kinematics studies, and numerical stress modeling demonstrate that lineaments observed northwest of the hinge of the large Crêt de la Neige anticline are indeed inherited normal faults. Our models indicate that these NE-SW oriented normal faults were induced by a basement fault located about 30 km southeast of the Crêt de la Neige. Additionally, numerical stress modeling demonstrates that these inherited structures were not reactivated during subsequent compression and were therefore passively displaced. This study will continue to explore basement inheritance on the Salève Mount and in the External Jura, focusing on areas such as the Heute, Quingey, and Lédonien faisceaux.

References

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Withjack, M. O., & Callaway, S. (2000). Active normal faulting beneath a salt layer: an experimental study of deformation patterns in the cover sequence. American Association of Petroleum Geologists Bulletin, 84(5), 627–651Lanphere, M., & Pamic J. 1992: K-Ar and Rb-Sr ages of Alpine granite-metamorphic complexes in northern Croatia, Acta Geologica, 22, 5-22.

Evidence of an active lacustrine subthermal vent in the Lake Geneva

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Abstract

A recent high-resolution multibeam bathymetric map of Lake Geneva shows multiple deep rounded depressions in the sediments (Dataset swissBathy3D, Federal Office of Topography swisstopo https://www.swisstopo.admin.ch/en/height-model-swissbathy3d). Most of these rounded structures at the lake bottom are irregularly-shaped and were interpreted as "kettle holes"-like features by Wildi and Hilbe (2015) and more recently, as craters formed by multi-phased fluid emissions related to the last deglaciation by Walt-Montenegro (2021). However, a specific crater structure shows a sharp and perfectly circular geometry (**Figure 1**), which is different from the other depressions. This crater was first studied and named "Bob" in July 2020 (*Walt-Montenegro, 2021*). It presents strong morphological similarities to the pockmark structures identified in Lake Neuchâtel (Reusch et al. 2015; Wirth et al., 2020).

Crater "Bob" is situated geographically in the offshore continuation of the N-S oriented Vallorbe-Pontarlier-Aubonne regional-scale strike-slip fault (**Figure 2**). Along this large-scale lineament, a well-developed hydrogeological system is documented (https://s.geo.admin.ch/khhapywfgixx). It includes several karstic springs and a series of onshore "pockmark-like" structures, which are known regionally as the "Bons de Mollens" or "Bons de Ballens" (Tribolet and Rochat, 1876; Pilloud, 2002; Letsch, 2020). As part of this system, the monitoring of a private groundwater spring also lying above this fault has shown a temporary but noticeable subthermal anomaly (A. Parriaux, oral communication).

A re-interpretation of 2D seismic lines suggests that the position of the lacustrine pockmark overlies a NE-SW thrust / back-thrust association forming a forced fold in the Mesozoic formations and recently named the "Radiophare anticline" in Marchant, 2024 and Marchant et al, 2024. The "Radiophare anticline" is subparallel to the trend of the Jura fold and thrust belt. The position of the pockmark marks the point where the Radiophare anticline intersects a lineament showing a transpressive apparent offset. We interpret this latter lineament as part of the Vallorbe-Pontarlier-Aubonne complex (Marchant, 2024; Marchant et al, 2024). This re-interpretation contrasts with those of Dupuy, 2006 and Dupuy et al., 2014, which suggest that the lacustrine pockmark would only overlie a set of small W-E strike-slip faults interpreted as part to the larger Vallorbe-Pontarlier-Aubonne fault system. The re-interpreted structural association generates a local uplift of the Mesozoic formations and localises a zone of thinning of the Cenozoic Molasse cover. At the location of the pockmark, Mesozoic limestones and above-lying Quaternary lacustrine sediments might even be in direct contact. Seismic interpretation situated 2.3 km away from the crater "Bob" suggests indeed a possible direct contact between Mesozoic limestones and above Quaternary lacustrine sediments. No displacement in Quaternary sediment was however detected from this seismic study (Dupuy, 2006) and no thermal activity was identified in July 2020 with prior CTD-measurements above crater "Bob" (*Walt-Montenegro, 2021*).

With this study, we report new results obtained in May 2024 that complement, and contradict, previous data. CTD measurements (**Figure 3**) done with an underwater ROV indicate a sharp increase in temperature above the crater "Bob" (up to 11°C at a depth of 150m) which contrasts with the lower water temperatures (ca. 7°C) observed above and in the external vicinity of the crater structure. Measurements of water conductivity in the crater "Bob" indicated values up to 1500 µS/cm, while the normal conductivity of the lake's water is around 300-325 µS/cm. Furthermore, water turbidity was detected at the bottom of the crater "Bob" when surrounding waters were not turbid at all.

These results suggest a fluid activity at the bottom of the lake. Combined to the different CTD measurements of July 2020 (*Walt-Montenegro, 2021*) we have indications that fluid activity might be irregular or seasonal, in relation with regional meteorology. This fluid activity at the bottom of Lake Geneva, as pointed by the existence of springs located on the same fault, might result from distant underground water circulations that are sourced in the Jura mountains of the Canton of Vaud through the faulted and karstified Mesozoic carbonate formations underneath the Molasse units. In any case, the structural position and morphology of crater "Bob" can be interpreted as a pockmark, similarly to craters in Lake Neuchâtel.

These results trigger new questions on the fluid circulation beneath the Molasse Basin and open new opportunities for the exploration of the relationship between fluid circulation and the structural geology of West Switzerland. They need to be confirmed by more detailed and systematic data.

Acknowledgements
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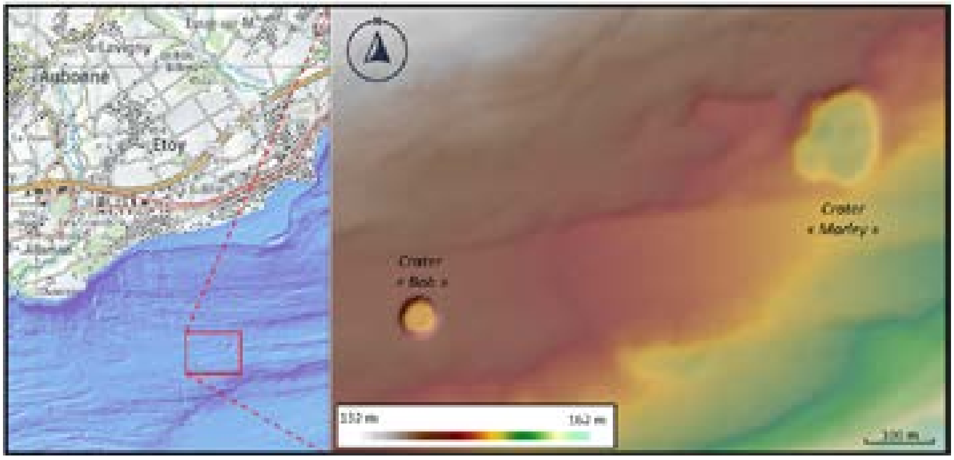


Figure 1: Left panel: geographical location of the right panel inset in Lake Geneva (Swizerland). Right panel: shaded-relief from multibeam bathymetry (Dataset swissBathy3D, Federal Office of Topography swisstopo https://www.swisstopo.admin.ch/en/height-model-swissbathy3d) reveals two nearby crater structures : perfectly rounded crater "Bob" interpreted as recent pockmark (this study and Walt-Montenegro, 2021) and its neighbouring irregular-shaped crater "Marley" interpreted as a deglaciation-related pockmark (Walt-Montenegro, 2021).

Figure 2: Conceptual 3D bloc diagram showing the structural position of remarkable hydrogeological features aligned along the North-South oriented Vallorbe-Pontarlier-Aubonne regional strike-slip lineament (vertical scale is exaggerated). The pockmark (crater "Bob") is located vertically above the intersection between this large-scale fault and a local zone of uplift defined by a smaller-scale NE-SW thrust and backthrust system.

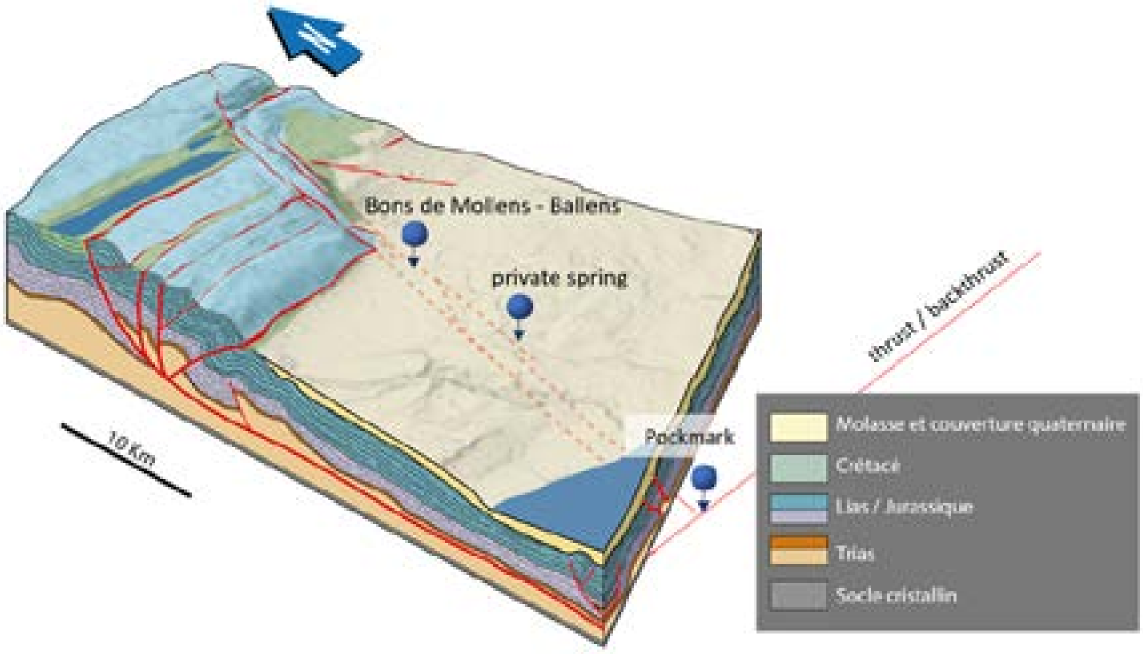
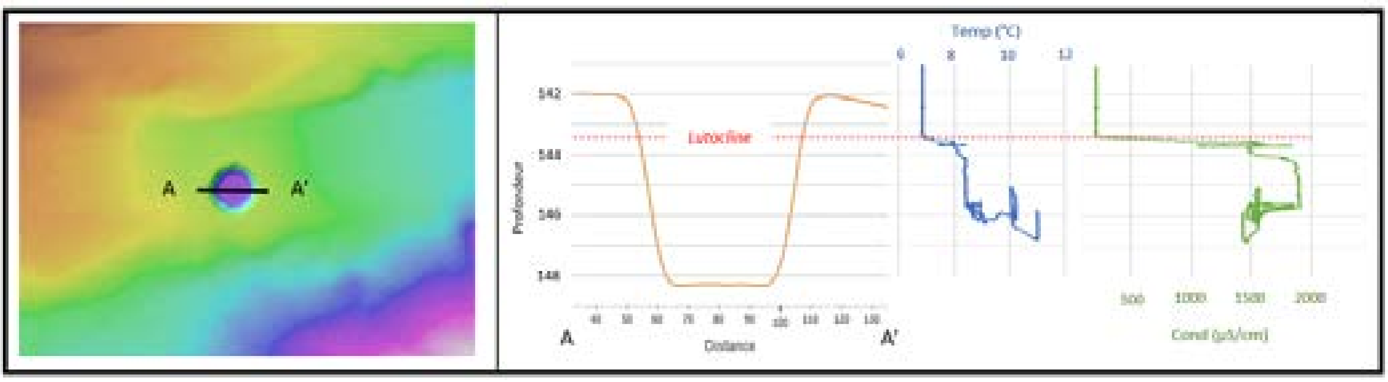


Figure 3: Results of preliminary measurements performed with CTD probe mounted on a remotely operated vehicle (ROV). Left panel : shaded-relief from multibeam bathymetry that reveal crater "Bob" morphology (Dataset swissBathy3D, Federal Office of Topography swisstopo https://www.swisstopo.admin.ch/en/height-model-swissbathy3d). Righ panel (from left to right): vertical depth profile versus distance [m] extracted from the bathymetry grid; water temperature profile [°C] and conductivity [µS/cm] measured by CTD probe inside the crater "Bob" structure. Note the sharp temperature and conductivity increases measured after passing the "lutocline" contact (zone of water turbidity transition).



Hydrostructural approach for a better comprehension of karstic hydrosystem – Transkarst Project

Victor Klaba[1], Hélène Celle[1], Flavien Choulet[1], Pierre Trap[1], Nicolas Carry[1], Luca Smeraglia[2], Jordan Labbe[1], Arnauld Malard[3]

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Abstract

Karstic hydrosystems are a crucial groundwater reserve. High degree of heterogeneity and anisotropy confer to the karst (1) a strong vulnerability against natural and anthropogenic contaminations and (2) a inherent hydrogeological complexity, which makes it a real challenge to study. To protect this vital resource, numerous investigative methods were developed. However, methodologies based on natural and artificial tracers are privileged at the expense of geological investigations. The purpose of our study is to put geology back in the spotlight by proposing a hydrostructural study. Arcier hydrosystem (Jura Mountains, France, TRANSKARST project) is taken as an example.

We thus propose an innovative methodology of delimitation of recharge area adapted to karstic springs using a multi-scale hydrostructural approach that combine: 1) a detailed field structural analysis at the outcrop, the geological structure and the whole hydrosystem scales, and 2) a 3D geo-structural and hydrological modelling through Visual Karsys software.

Our approach thus allows to define the geometry of the two aquifers (Middle and Upper Jurassic) separated by an impermeable layer (Oxfordian marl) and to determine precisely the geometry of the fracture network that connects them. These results combined with hydrodynamic data determine the degree of connection between the two aquifers during high and low water periods. All analysis are integrated in a 3D numerical model that improves our understanding of the functioning of the whole Arcier hydrosystem, what could be extended to other karstic systems.

Insights into Jura fold-and-thrust belt structuration via U-Pb on carbonates

Antonin Bilau[1, 2], Flavien Choulet[2], Luca Smeraglia[3], James Richard[2], Jean-Pierre Sizun[2], Xavier Mangenot[4], Abel Guihou[5], Pierre Deschamps[5]

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Abstract

The Jura fold-and-thrust belt, characterized by its arcuate shape, formed in response to the far-field effects of Alpine compression during the Miocene (Sommaruga, 1996; Becker, 2000). Tectonic shortening affected the sedimentary succession, generating thrusts and folds with N-S striking in the SW Jura to E-W striking in the NE Jura (Sommaruga, 1996). This deformation localized the stress while simultaneously forming plateau areas that appear to be only slightly deformed.

Recent carbonate U-Pb dating revealed a SE-NW evolution of thrusting between 14.5 Ma and 7.5 Ma, interpreted as in-sequence thrusting leading to the Jura imbrication (Looser et al., 2021; Smeraglia et al., 2021). In addition to these contractional features, several NNW to NNE strike-slip faults are commonly observed in the area. Some of these faults clearly offset the thrusts and folds and are interpreted as tear faults (Sommaruga, 1996), while others seem to crosscut the deformed sedimentary succession, connecting to the Rhine-Bresse Transfer Zone fault system. Absolute carbonate U-Pb dating on a selection of these faults mirrors provides pre-, syn-, and post-compression ages (from 48-45 Ma to 4 Ma; Smeraglia et al., 2021), suggesting a more complex structural evolution prior to compression and continued deformation after the main thrusting events.

In this study, we obtained eleven dates on fault structures in the NE Jura: four dates range from 46.9 ± 1.3 to 33.1 ± 1.9 Ma, as well as some fractures around 37 Ma and five dates range from 9.3 ± 1.5 to 6.1 ± 1.2 Ma, indicating multiple deformation events and reinforcing the established chronology. Further investigations on fluid circulations using stable and clumped isotope analyses are planned.

Investigating sub-seismic fracture networks in the Muschelkalk Group in the Wutach Gorge (Tabular Jura, DE), towards a revised CO2 storage potential assessment in Switzerland

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Abstract

Switzerland aims to reach net-zero CO2 emissions by 2050 (BAFU, 2021). Implementation of geological storage of CO2 and geothermal heat mining to help achieve this aim requires reservoir properties to be assessed both locally (at sub-seismic or meter-scale) and regionally. The structural and permeability architectures of the target reservoirs are essential input for numerical models that can be used to assess storage and production potential, minimize fluid injection and extraction uncertainties, and reduce exploration risks. The Middle Triassic Muschelkalk Group including the Schinznach Formation is one of the key potential aquifers for gas storage and hydrothermal systems identified in Switzerland (Chevalier et al., 2010). Whereas its matrix permeability is relatively well known (Diamond et al., 2019), the extent of its fracture permeability and the structural controls on these fractures are poorly understood.

This study aims to assess the style and intensity of brittle fracture networks in the Schinznach Fm. at sub-seismic scale and to describe and explain their regional variability. Outcrops of the unit in southern Germany are used in conjunction with available drill hole and geophysical data to model fracture networks at ~800–1200 m depth in northern Switzerland. The initial field study area, Wutach Gorge, is located in the Tabular Jura and provides accessible rock cliff exposures along 5–12 km-long transects in E–W and N–S directions partly crossing regional fault strands of the Freiburg–Bonndorf–Bodensee Fault zone.

This ongoing work contributes regional insight into fracture networks in support of a proposed *pilot* CO2 injection test into the Schinznach Formation via an existing exploration borehole in northern canton Zurich (Trüllikon). A feasibility study (Diamond et al., 2023) assessed the reservoir properties at Trüllikon by building discrete fracture network models and permeability scenarios from a combination of rock-matrix properties, vertical drill hole fracture logs, one horizontal fracture log from another nearby drill hole, and results from hydraulic tests. We draw comparisons between these results and new outcrop data to provide an understanding of the lateral variability of sub-seismic scale structures and fracture networks, including their dependence on regional deformation zones. This should provide a more robust basis for future exploration for both CO2 storage and geothermal energy.

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Multi-scale structural mapping and analysis of natural fractures of Creux-Du-Van (Central Internal Jura)

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Abstract

Creux-du-Van is a prominent geological and geomorphic feature within the Central Internal Jura Fold and Thrust Belt. The amphitheater-shaped cliffs, over 160 meters in height, provide almost 3D exposure of folded and fractured Upper Jurassic (Upper Malm) limestones. The formation of the Creux-du-Van cliffs was primarily controlled by glacial erosion and potentially the presence of brittle tectonic features such as faults or fracture zones. When permeable, these structures can direct meteoric and groundwater flow within the Upper Jurassic unit. Water-rock interaction is evident in enlarged karstic features, particularly fracture-aligned dolines.

Our study investigates the multi-scale geometry of natural fractures at Creux-du-Van. We aim to link the formation of various fault and fracture sets to the tectonic evolution of the Jura Mountains and gain insights on the potential controls of these fractures on the development of preferential fluid flow paths in the Creux-du-Van region. We conducted a terrestrial LiDAR survey of the Creux-du-Van cliffs, from which a 3D point cloud (with an approximate average density of 110 points/m^2) was generated and aligned with a publicly available digital elevation model (Swisstopo, 2011)). This georeferenced 3D dataset enabled us to digitally map and measure the orientations of approximately 600 structures (i.e., faults and joints) and sedimentological features (i.e., bedding surfaces) along the cliffs which are normally physically inaccessible. Approximately 200 direct field measurements, as well as observations of fracture kinematics, were made along the tops of the cliffs, complementing the point cloud measurements.

To analyze the fracture dataset, the Creux-du-Van cliffs were subdivided into sectors that represent different structural positions of a regional, NW vergent, asymmetric fold (the Nouvelle Censière – Montagne de Boudry anticline; here considered as a first-order fold). Preliminary analyses revealed the presence of: (1) meters to sub-meter-scale conjugate sinistral N-S and dextral NW-SE to ESE-WNW shear fractures, the orientations and kinematics of which are consistent with the km-scale N-S striking and ESE-WNW striking fault zones bounding the Creux-du-Van area to the west and northeast; (2) a dominant NW-SW striking fracture set interpreted from the point cloud, which matches the NW-SE orientation of tensile to hybrid fractures directly observed in outcrop; (3) NW dipping low-angle thrust faults observed both in the point cloud and directly in outcrop; (4) NE-SW striking normal faults (with less than 10 m offset) present only in the outer arc of the first-order fold crest; and (5) distinct fracture patterns in the northern cliff face that forms a subvertical to overturned limb of the first-order fold. The observations (1) to (4) above are consistent with the regional NW-SE directed maximum horizontal stress associated with formation of the Central Internal Jura. Their relative timing and link to different deformation phases of the formation of the Jura Fold and Thrust Belt will be the subject of future investigations, which will also explore how these fractures influenced paleo-fluid flow.

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Systematic 3D geological modelling of the Jura fold-and-thrust belt (Switzerland). Part 1/2: Aims and methodology

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Abstract

The Swiss Geological Survey (SGS) has started within the scope of the Jura3D project a systematic 3D geological modelling of the Jura fold-and-thrust belt (FTB) in north-western Switzerland. The main base data set for the realisation of Jura3D is the semantically and geometrically harmonised vector data of the Geological Atlas of Switzerland 1:25000. In the subsurface, however, the data have not yet been fully harmonised. Therefore, the geological profiles, borehole data and geophysical data form a heterogeneous data set that varies significantly in terms of data density, recording quality, level of detail and, in particular, geological interpretation. For Jura3D – as for other 3D geological models – a comprehensive geological interpretation in the model area, taking into account the available data, is essential and at the same time the greatest challenge.

Jura3D consists of a dense network of intersecting geological profiles (fence diagram) oriented perpendicular and parallel to the strike of the Jura FTB, including modelled fault surfaces and a fully modelled lithostratigraphic reference horizon. Jura3D thus forms a harmonised 3D geological model with a high level of detail that can be easily controlled and adjusted in the future.

The 3D geological modelling is divided into eight model areas. The majority of the work is carried out by external contractors in individual, quasi-independent areas, with the coordination and supervision provided by the SGS. In order to guarantee a harmonised interpretation between the sub-models of the Swiss Jura FTB, a set of clear and consistent guidelines has been introduced: 1) Tectonic concept, 2) Stratigraphic concept and 3) Modelling methodology. Furthermore, balanced reference sections were constructed at each model boundary to ensure consistent and uniform interpretation across the eight model areas.

In addition to the division into eight model areas, the Swiss Jura FTB is subdivided into tectonic deformation cells. This helps to structure Jura3D into smaller units (Jordan et al., 2023). Each deformation cell is defined as a structural unit or tectonic nappe with a set of common, structurally related tectonic features to support the modelling process and is laterally limited by major strike-slip faults and frontally by a major thrust (Mosar & Jordan, 2022). This approach guarantees the creation of a harmonised three-dimensional model of the Swiss Jura FTB.

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Systematic 3D geological modelling of the Jura fold-and-thrust belt (Switzerland). Part 2/2: Current state of implementation

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Abstract

Following the presentation of the aims and methodology of Jura3D, we focus on the first results of the 3D geological modelling of the Swiss Jura fold-and-thrust belt (FTB). The modelling work started in September 2022 in the south-western part of the Swiss Jura FTB. This allows us to present the first preliminary results of the geological subsurface interpretations from the St-Cergue – Morez strike-slip fault, the cylindrical SW–NE oriented Mont Tendre and Mont Risoux anticlines, the prominent Aubonne – Pontarlier strike-slip fault to the Chasseron anticline. This is the first time, a uniform geological three-dimensional interpretation of the subsurface has been produced in this extensive area. The 3D geological modelling will be extended to the eastern end of the Swiss Jura FTB in the coming years.

The 3D geological model visualises a fence diagram, which consists of a dense network of modelled geological profiles that intersect at regular intervals, and the associated fault surfaces. The deformation cells introduced for Jura3D in the Swiss Jura FTB are recorded in the 3D geological model and can thus be displayed in profile, map and 3D view. The lithostratigraphic model units in the geological profiles range from the Base Mesozoic to the base of the Molasse Supergroup. The model can therefore extend above the present-day topography. For each deformation cell, it was assumed that the thicknesses of the lithostratigraphic model units are constant. The lithostratigraphic model units of Jura3D are specified in detail in the stratigraphic guidelines of the project.

Tectonique de l'avant-pays alpin : que se cache-t-il sous les lacs ?

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Abstract

La plupart des modèles tectoniques de l'avant-pays alpin, incluant la chaîne jurassienne et le bassin molassique, sont basés sur la géologie de surface et sur des données géophysiques pour les parties profondes. Mais sous les grands lacs ces données sont absentes ou de piètre qualité.

Pour le lac Léman, la prospection d'hydrocarbures a contribué à acquérir plusieurs lignes de sismique-réflexion entre 1964 et 1997. Leur qualité est généralement si médiocre qu'elles n'ont souvent pas été interprétées. Les raisons de cette mauvaise qualité sont la présence de multiples, d'une épaisseur de sédiments quaternaire très variable et d'émanation de gaz. En revanche, des lignes sismiques à haute et ultrahaute résolution ont permis d'imager les dépôts quaternaires de manière remarquable sur une grande partie du lac. Pour le lac de Neuchâtel, aucune campagne de prospection pétrolière n'a eu lieu mais la sismique de haute et ultrahaute résolution a aussi apporté une bonne imagerie du Quaternaire.

La présente étude a cherché à approfondir ces interprétations et a permis de mettre en évidence des structures tectoniques enfouies sous l'eau et les sédiments quaternaires. Dans la partie Est du lac Léman, un chevauchement a généré sous les Préalpes un dôme anticlinal de large amplitude qui n'a pas d'équivalent au front de la chaîne alpine.

Juste au large du delta de l'Aubonne, la présence à faible profondeur du toit du Mésozoïque avait été mise en évidence par la sismique haute-résolution et interprétée comme liée à la faille d'Aubonne-Pontarlier (Dupuy et al .2014). Elle paraît plutôt due à une structure anticlinale faillée chevauchante qui se dessine sous le lac le long de La Côte avec un axe NE-SW et passant par le radiophare de Saint-Prex. Le chevauchement se termine vers le Nord-Est à la hauteur de Préverenges où un forage a découvert de l'eau sub-thermale. Une rétro-faille de cette structure passe par un pokemark actif juste dans la prolongation de la faille Aubonne-Pontarlier (Giorgis et al. 2024).

Une faille inverse chevauchante, parallèle aux structures jurassiennes, se suit dans le centre du lac de Neuchâtel et est probablement à l'origine du haut-fond de la Motte. Cette structure et celle du radiophare sont dans une position tectonique et une orientation identique au Salève, mais avec une déformation de moindre amplitude. Les vaudois et les neuchâtelois auraient donc aussi leur Salève, mais caché sous les lacs.

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Slope-design et calcul statique dans un massif rocheux plissé, chevauché et fracturé (Carrière des Granges, Le Locle)

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Abstract

En 2017, un éboulement d'environ 70 000 m³ de rocher s'est produit dans le front de taille de la Carrière des Granges au Locle (massif du Jura, Canton de Neuchâtel, Suisse). Cet évènement a mis en évidence une importante détérioration de l'ensemble du front de taille de cette carrière, incompatible avec le projet d'y installer le portail du tunnel de contournement du Locle (projet H20 puis N20).

Pour stabiliser le front d'excavation, nous avons proposé de reprofiler le massif rocheux (slope-design). La géométrie du reprofilage étant fortement conditionnée par les contraintes du projet, le MO a opté pour un renforcement des fronts.

Les logiciels de calcul par analyse de l'équilibre limite selon la méthode des tranches fonctionnent couramment avec le critère de rupture de Mohr-Coulomb. Nous présentons notre approche de calcul utilisée pour vérifier la stabilité d'un versant rocheux présentant d'importantes déformations tectoniques (plis et chevauchements), mais pour lequel nous avions très peu d'informations quantitatives. En effet, des chutes de pierres récurrentes nous empêchaient l'accès à une grande partie du front d'excavation.

Une campagne d'investigations géotechniques complémentaire (forages, analyses en laboratoire et analyses structurales) ont permis de récolter les données quantitatives nécessaires à l'élaboration d'un modèle géologique-géotechnique en trois dimensions pour un massif rocheux fissuré de manière homogène. Le modèle comprend l'estimation du GSI (geological strength index, Merinos and Hoek, 2007), la détermination des paramètres de Hoek and Brown et le calcul des paramètres de Mohr-Coulomb correspondants (Hoek at al., 2002).

Sur la base de la rétro-analyse de l'éboulement et de l'expertise du projet, les familles de discontinuités persistantes ont été intégrées dans ce modèle. Les paramètres de Mohr-Coulomb correspondants ont été ainsi corrigés selon l'agencement et la persistance des familles de discontinuités, afin d'exprimer les paramètres géomécaniques d'un massif rocheux fissuré avec des discontinuités persistantes (Einstein et al., 1983 ; Merrien-Soukatchoff et Gunzburger, 2002). Ces calculs statiques ont permis de vérifier la stabilité globale du massif rocheux et de dimensionner les ancrages actifs. Les ancrages passifs (clous) ont été dimensionnés à l'échelle des bermes. Au vu des incertitudes géologiques et géotechniques du site, nous avons préconisé l'application de la méthode observationnelle et nous avons élaboré un programme de surveillance pendant la réalisation des travaux, puis durant l'exploitation du tunnel.

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Hydro-geophysical monitoring in the Jura mountain

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Abstract

The Jura is a faulted and karstified region which current deformation is the subject of debate. A regional seismic network, JURAQUAKE (OSU THETA), has been deployed in eastern France in 2018, supplementing the Epos-fr network. Some of the seismic stations have been installed above and into the unsaturated zone of a karst aquifer and coupled to an existing hydrogeological observatory (Fourbanne, Doubs ; JURASSIC KARST - SNO KARST). Additionally, 500 meters of fiber optic cable have been deployed along the underground conduit and connected to a Distributed temperature sensing system. A very-high resolution 3D scan of the cavity was also acquired with a long-range Zeb-REVO to image underground geological structures. The objective of this new multidisciplinary approach is to be able to characterize fluid transfer within this highly heterogenous reservoir and investigate its contribution to crustal deformation.

Eocene to Oligocene tectonic inheritance in the front range of the Jura fold-and-thrust belt (Avant-Monts, Besançon, France)

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Abstract

The Jura mountains are considered as a classic example of a fold-and-thrust belt formed via thin-skinned deformation during the middle Miocene to Pliocene Alpine convergence. The Mesozoic sedimentary cover (from Triassic to Cretaceous) is decoupled from the basement along a basal décollement in the Triassic evaporites. Thrust faults exposed at the surface are believed to be linked with this large-scale basal décollement.

Recent U-Pb dating of syn-tectonic calcite mineralization (veins, slickenslide and breccia cements) in thrusts and tear faults confirm Neogene age of deformation with in-sequence thrust propagation from ca. 15 Ma to 4 Ma (Looser et al., 2021; Smearglia et al., 2021, Madritsch et al., 2024). However, Smeraglia et al. (2021) also reported an older pre-orogenic Eocene faulting episodes at ca. 44-48 Ma related either to the far-field effect of Alpine convergence or of the Pyrennean collision, suggesting that the Jura finite geometry is polyphased. Schopfler et al. (2024) have conducted a detailed structural analysis using 3D seismic data in the easternmost tip of the Jura belt and concluded that basement-rooted normal faults related to the opening of Carboniferous to Permian basins were reactivated and propagated into the Mesozoic cover, questioning the classic concept of thrust faults rooted at the base of the Mesozoic cover.

The so-called « Avant-Monts » zone, located at the front of the Jura near Besançon (France), is located in an area where the role of tectonic inheritance on the formation of the Jura might be critical. This area is characterized by the presence of hidden Permian grabens recognized in historical boreholes (e.g. the Gendrey borehole), and by inferred major crustal faults, oriented ~N070 resulting in the formation of the Miserey horst (eastern prolongation of the la Serre massif horst, where the Variscan basement is exposed), as well as ~N010 to N030 faults (Schori, 2021). The Avant-Monts zone also coincides with the Rhine-Bresse left-lateral transtensive transfer zone formed during the Oligocene European continental rifting. This Oligocene rifting is mainly defined by the Ognon normal fault characterized by a vertical offset up to a kilometer (Schori, 2021). In the eastern part of the Avant-Monts, the Ognon graben and normal faults are interpreted to be overthrusted by the Mesozoic sequence thanks to the Chailluz thrust, which would correspond to the most frontal Pliocene thrust of the Jura.

The studied area is divided in three structural domains based on deformation style and exposed lithologies. The western part of the Avant-Monts is defined as the La Serre zone following Schori (2021). In this area, the Mesozoic cover, that is still attached to the Triassic evaporites (Madritsch, 2008), is mostly horizontal and affected by N070 basement faults leading to a horst and graben geometry. The central part corresponds to the Corcondray – Miserey fault system that is characterized by a high density of N020-030 faults along which Triassic (Late Keuper) formations are exposed. The Eastern part, defined as the Chailluz domain, is characterized by a more classic fold-and-thrust geometry. In both Corcondray – Miserey fault system and Chailluz domain, exposures and historical borehole suggest that the basement and its cover were pre-structured into a host-and-graben geometry prior to the Neogene compression. Finally, these three domains are bounded to the north by the N070 Ognon normal fault.

Preliminary in-situ LA-ICP-MS U-Pb dating of calcite veins associated with faults from the three domains and the Ognon fault have been conducted. Three localities from the N020-030 faults of the Corcondray-Miserey fault system give very consistent late Eocene - early Oligocene ages ranging from 32 to 38 Ma. On five samples located along or near the Ognon fault, two distinct group of ages have been obtained : an early Oligocene age ranging from 32 to 35 Ma, very consistent with ages obtained on the N020-030 faults and middle Eocene ages, ranging from 39 to 47 Ma. For instance, the fault juxtaposing the Upper Jurassic and Upper Triassic formations near Miserey gave an Eocene age at 44 Ma. In all the dated samples, we have not encountered Miocene to Pliocene ages related to the formation of the Jura.

To conclude, we propose that the finite geometry of the Avant-Monts is largely predetermined by successive Middle Eocene (ca. 40-45 Ma) and Early Oligocene (ca. 32-34 Ma) tectonic events. The middle Eocene event is related to the far field tectonic effect of Alpine orogeny and the onset of the European Cenozoic Rift System. This event may have been responsible for the formation of the Ognon normal fault and the N070 horst and graben geometry. The early Oligocene event is rather related to the development of the transfer zone that accommodates the opening of the major Bresse and Rhine Oligocene grabens. It is very likely that these Eocene and Oligocene structures have been partially reworked during Miocene and Pliocene convergence, despite the absence of radiogenic ages along the studied structures.

Projet tunnelier de la Ligne Directe CFF entre Neuchâtel et La Chaux-de-Fonds

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Abstract

Le projet de la Ligne Directe ferroviaire des CFF (Chemins de Fer Fédéraux) permettra de connecter en 15 minutes (contre 28 actuellement) les deux principales villes du canton neuchâtelois que sont Neuchâtel et La Chaux-de-Fonds. Longue de 16 kilomètres, les infrastructures de cette nouvelle ligne ferroviaire se présenteront en grande majorité en tunnel (90%).

Le bureau d'études MFR GEOLOGIE-GEOTECHNIQUE SA a été mandaté par les CFF à partir de 2022 pour l'étude géologique et géotechnique en phase d'Avant-Projet, et notamment pour les sections tunnelières que représentent le « tunnel de Chaumont » au Sud et le « tunnel de la Vue-des-Alpes et du Mont-Sagne au Nord ».

Ce projet complexe a permis de traiter de nombreux domaines appliqués de la géologie.

Dans le cadre de cette étude, un total de 2 430 mètres linéaires de forages carottés a été mené à bien. Certains d'entre eux furent menés jusqu'à 500 mètres de profondeur. Ils ont permis de recouper l'ensemble des formations géologiques présentes dans la Haute-Chaîne du Jura, des marnes à gypses du Keuper jusqu'à la molasse Tertiaire, en passant par les roches sédimentaires du Jurassique et du Crétacé inférieur.

Au-delà des considérations lithologiques, les tracés tunneliers recouperont plusieurs entités géostructurales anticlinales (Mont-Chaumont, Monteperreux et Mont-Sagne) et synclinales (Val-de-Ruz) ainsi que de nombreuses failles chevauchantes et décrochantes témoins d'une tectonisation régionale dense.

Le système karstique que traverseront les ouvrages tunneliers est également un sujet sensible ayant été traité avec attention, notamment vis-à-vis des problématiques liées à la protection des eaux souterraines et à la gestion des eaux de drainage.

L'exploitation de ces carottes et des nombreux essais « *in situ* » menés à bien à cette occasion, ont permis de définir un modèle géologique prévisionnel des plus précis.

Un scanning optique des parois rocheuses a été réalisé en forage à chaque fois que ce fut nécessaire permettant d'apprécier les différentes discontinuités (plans de fractures et structures lithologiques) et d'en mesurer leur pendage et orientation. Cet essai fut accompagné d'une diagraphie sonique dite « *Full Wave Sonic* » utilisée pour obtenir des informations sur les propriétés géomécaniques des roches traversées par un forage comme le module d'élasticité.

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H

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HESSENAUER	Marc	MFR Géologie-Géotechnique
HOMBERG	Catherine	Sorbonne Université – ISTeP
HUSSON	Eglantine	BRGM DGR-GBS

I

INVERNIZZI	Joël	Université de Fribourg – Département de Géosciences

J

JACMAIRE	Jean-Charles	MFR Géologie-Géotechnique
JEANNIN	Pierre-Yves	ISSKA
JORDAN	Peter	Grüner

K

KLABA	Victor	Université de Franche-Comté – Chrono-environnement

L

LECLERE	Henri	Université de Franche-Comté – Chrono-environnement
LORIDANT	Ulysse	45-8 ENERGY

M

MAILLOT	Bertrand	CY Cergy Paris Université – GEC
MARCHANT	Robin	Muséum cantonal des sciences naturelles, Lausanne
MARRO	Adeline	Université de Fribourg – Institut des Sciences de la Terre
MOSAR	Jon	Université de Fribourg – Département de Géosciences

N

NUSSBAUM	Christophe	Swisstopo – Service géologique national – Laboratoire souterrain du Mont Terri

P

PIETSCH	Johannes	Schweizer Salinen AG
POLASEK	David	Hydro-Géo Environnement

Q

QUIQUEREZ	Amélie	Université de Bourgogne – ArTeHiS

R

REILE	Benoît	CABINET REILE, Besançon
RIGAUD	Sylvain	Canton du Jura
ROTA	Hugo	MFR Géologie-Géotechnique

S

SAUSSEREAU	Mario	Université de Franche-Comté – Chrono-environnement
SCHNEEBERGER	Raphael	Nagra
SCHORI	Marc	
SIGNER	Salomè	Swisstopo – Service géologique national
SMERAGLIA	Luca	CNR Rome – IGAG

T

TRAP	Pierre	Université de Franche-Comté – Chrono-environnement

U

URSPRUNG	Anina	Swisstopo – Service géologique national

V

VALLET	Aurélien	BRGM Dijon
VALLEY	Benoît	Université de Neuchâtel – Centre d'hydrogéologie et de géothermie
VAN DER WOERD	Jerome	CNRS / Université de Strasbourg – ITES
VIVIER	Margot	BRGM Montpellier

Z

ZUCCA	Alexander	Université de Fribourg – Département de Géosciences

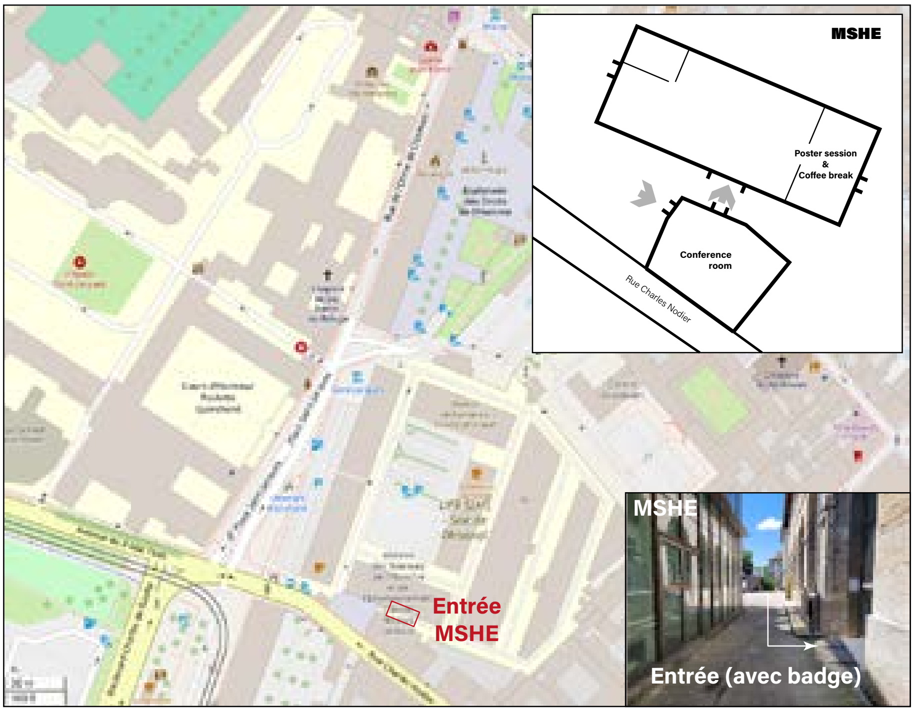
Informations

Conference venue

The conference will be held at the Maison des Sciences de l'Homme et de l'Environnement (MSHE) Claude Nicolas Ledoux in Besançon.

Pedestrian acces:
Esplanade Germaine Tillion
1 rue Charles Nodier
25000 Besançon

Oral presentations will take place in the conference room, while coffee breaks and poster sessions will be held in the exhibition hall.



IMPORTANT : It is forbidden to eat or drink outside the exhibition hall (poster session room). Thank you in advance.

Gala dinner : Wednesday 9th October

The gala dinner will be held at la Péniche Le Chaland at 19:30: Pont Bregille, avenue Edouard Droz, Parc Micaud, 25000 Besançon

Notes

Notes