MULTI-SCALE STRUCTURAL MAPPING AND ANALYSIS OF NATURAL FRACTURES OF CREUX-DU-VAN

JEFTER CALDEIRA, ANINDITA SAMSU, AYOUB FATIHI

Faculté des géosciences et de l'environnement – UNIL – Lausanne – Switzerland

UNIL | Université de Lausanne

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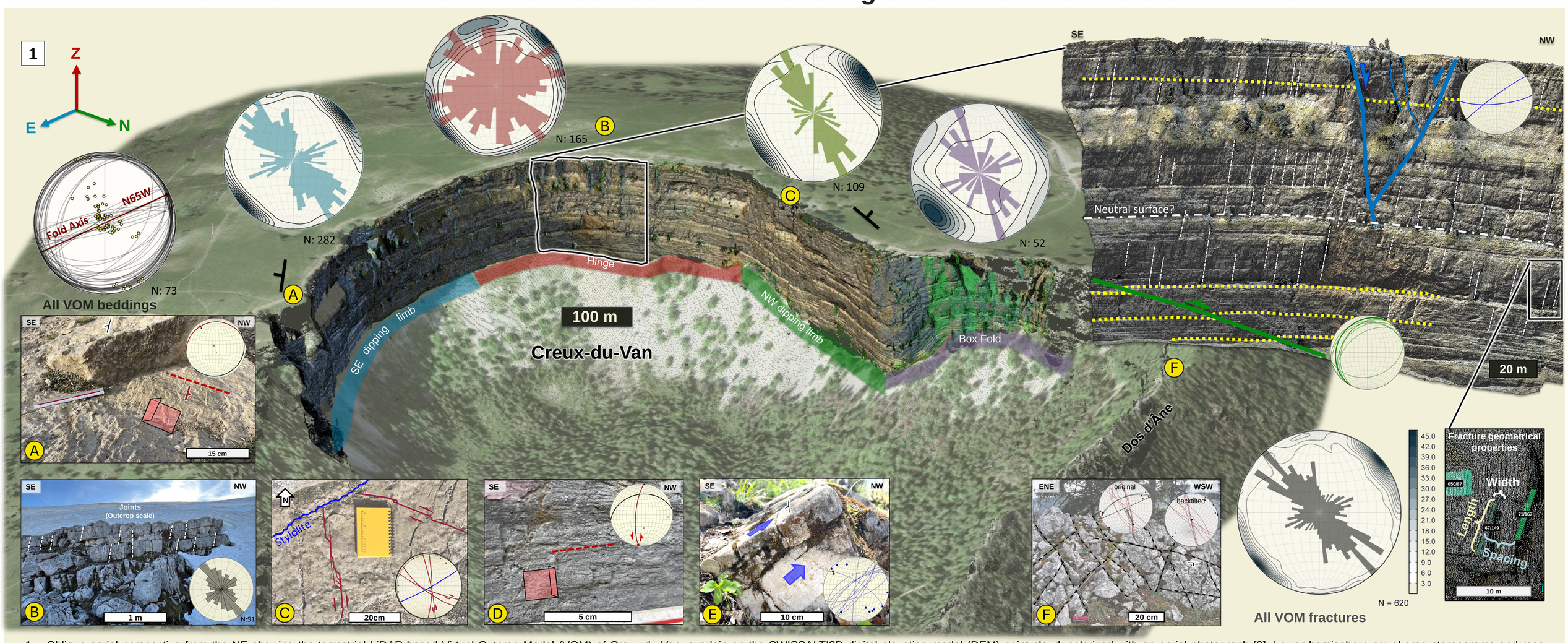
How do meter-scale fractures at Creux-du-Van relate to regional structures in the Central Internal Jura?



1 – Oblique aerial perspective from the NE showing the terrestrial LiDAR-based Virtual Outcrop Model (VOM) of Creux-du-Van, overlain on the SWISSALTI3D digital elevation model (DEM) point cloud, colorized with an aerial photograph [9]. Lower hemisphere equal-area stereograms and rose diagrams represent bedding and fracture orientations from the VOM, interpreted for each sector. Sectors were determined based on their position within a higher-order fold Nouvelle Censière (NC) Anticline (i.e., SE dipping limb, hinge, NW dipping limb, and box fold). A zoomed-in view of the cliff at the Hinge region highlights normal axial faults in the outer arc and thrust faults in the inner arc of the NC Anticline. Another detailed view at meter scale demonstrates how geometrical properties of fractures were measured in this study. Field photographs (A to E) display planar and linear kinematic indicators used in the paleostress analysis, joints were excepted from this analysis, with the associated stereonets showing shear fractures (red), bedding planes (black), and stylolites (blue). Photograph F, taken at the Dos d'Âne, shows steep to vertical bedding and two fracture sets whose intersection is orthogonal to bedding. Note that after back-tilted, the fracture sets appear to form a conjugate set resembling those in image C.

Why study fractures at Creux-du Van?

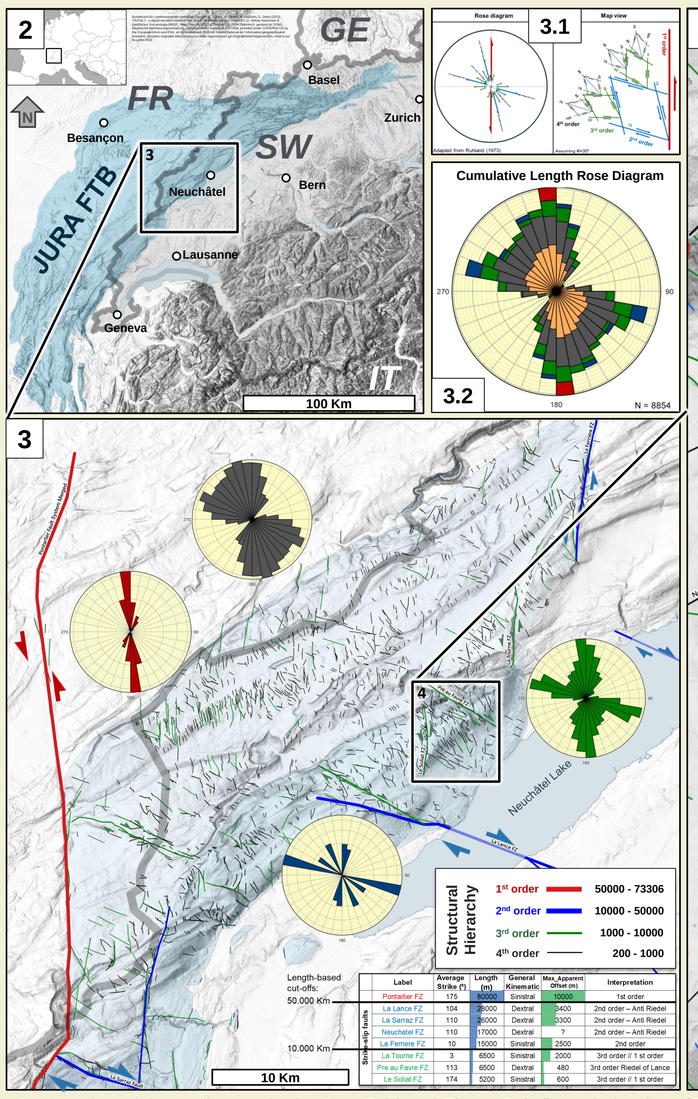
- **Exceptional** three-dimensional (3D) **exposures** of fractured Upper Jurassic limestones.
- Key for understanding **folding, faulting,** and **paleostress** orientations, placing local structures in the context of regional tectonics
- Critical for geoenergy exploration and development, as **permeability and fluid flow** in the Jura Mountains is primarily controlled by **open fractures** and karstification in Mesozoic limestones.

Data & Methods – A Multi-Scale Approach

- **Hierarchical tectonic lineaments analysis** of publicly available DTM [9] and compiled regional tectonic/geological maps [1,7,8,10].
- Acquisition, processing and digital interpretation of tectonic structures on a **Terrestrial LiDAR based Virtual Outcrop Model (VOM).**
- **Field-based** observations along the cliff edges and surroundings of Creux-du-Van, focused on **kinematic and paleostress analysis**.

Observations & Results

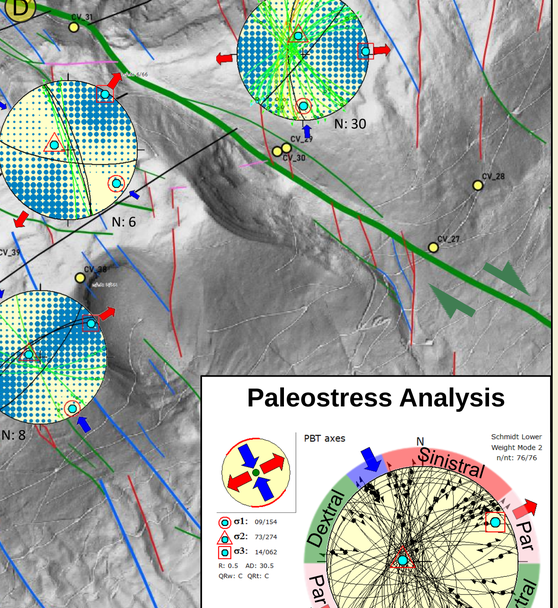
1. **Conjugate shear fractures**: Sinistral N-S to NE-SW and dextral NW-SE to ESE-WNW fractures at the outcrop scale, consistent with regional fault zones in terms of orientation and kinematics; some veins and fault planes are calcite-mineralized (1C, 1D and 1F).
2. **NW-SE joints** and veins at the VOM's & outcrop scale represent background fractures (1B);
3. **Folded bedding** mapped on the VOM with a sub-horizontal fold axis trending N65W (1).
4. **Low-angle NW-dipping thrust faults** observed in both VOM and outcrop, consistent with the Val-de-Travers thrust zone and sub-parallel to the regional fold axis (1A).
5. **Axial, NE-SW striking normal faults**: Less than 10 m offset, present in the outer arc of the NC anticline's first-order fold crest (1).
6. **NE-SW striking subvertical stylolites**: Observed at scales from sub-meter to outcrop (1E).
7. **The steep fold limb** in the Dos d'Âne region exhibits a meter-scale conjugate fracture pattern, with **intersections orthogonal to the bedding** (1F).



2 - Location of the study area in the Jura Fold and Thrust Belt (boundaries from [7]). 3 – Structural hierarchy of lineaments in the Eastern Central Internal Jura (ECIJ),some of which appear to be strike-slip faults, compiled and modified from maps at the 1:500.000 [7], 1:50.000 [1], and 1:25.000 [8,10] scales Length-based cut-offs define the order of the lineaments (e.g., 1st order, 2nd order, etc). (see table). 3.1 Schematic rose diagram and traces of faults in a Riedel system [11]. 3.1 – Cumulative length-weighted rose diagram for the ECIJ, containing all structures lineaments shown in 3. 4 – Zoomed-in map of the Creux-du-Van region, with the hill-shaded SWISSALTI3D DEM [9], showing structural lineaments (modified from [10]) bounded by 3rd order faults: Sinistral N-S striking Le Soliat Fault Zone, Dextral NW-SE striking Pré au Favre Fault Zone, and the NE-SW striking Val-du-Travers thrust fault. Lineaments are colored according to azimuth ranges, determined from paleostress analysis using Win_Tensor [2]. Both paleostress inversion techniques (PBT axes, Right Dihedron) yielded similar results. The Frohlich diagram highlights a dominant strike-slip regime for this dataset.

Key Outcomes

- Orientation and kinematics of strike-slip faults in the ECIJ (3) are comparable with the Riedel system model [11], providing a **framework for the hierarchy of brittle structures** at Creux-du-Van.
- The Virtual Outcrop Model enables **precise 3D fracture characterization** and geometric measurements, even in inaccessible areas.
- As for the Eastern Jura [5,6], back-tilting of the structural measurements at Dos d'Âne reveals **a conjugate fracture set** that is interpreted to have been active **pre- to syn-folding**.
- Results from field observations and **kinematic analysis** (4) imply a NW-SE directed maximum horizontal stress, consistent with previous studies [3,7]. Conjugate faulting in the study area would normally be associated with a vertical σ2 and horizontal σ3 (5), while a horizontal σ2 and vertical σ3 is associated with thrusting (and related folding). Therefore, **a switching of σ2 and σ3 orientations** throughout the evolution of folding and fracturing may have occurred.
- The only **local paleostress anomaly** was found along the NW-SE striking 3rd order Pré au Favre fault zone, where **meter-scale fractures appear to have been rotated clockwise.**



5 – Preliminary conceptual model illustrating tectonic stages and associated principal stress orientations in the study area.

References

[1] BRGM, 2004, Bureau de Recherches Géologiques et Minières; [2] Delvaux et al., 2003, Win_Tensor Geological Society of London Special Publication; [3] Homberg et al., 2002, Tectonophysics; [4] IGN, 2018, RGE ALTI®; [5] Madritsch, 2015, Swiss Journal of Geosciences; [6] Madritsch et al., 2024, Tectonics; [7] Schori, 2021, PhD Thesis, University of Fribourg; [8] Swisstopo, 2024, GeoCover Geological Vector Datasets V3; [9] Swisstopo, 2011, Digital Elevation Model swissALTI3D; [10] Pasquier et al., 2013, Atlas geologique de la Suisse – 1163 Travers; [11] Ruhland, 1973, Sciences Géologiques Bulletin.

Next Steps

- Develop conceptual model of the multi-scale structural evolution of Creux-du-Van based on fracture geometries and kinematics presented here.
- Conduct optical and CL analysis of calcite fills and assess U-Pb dating potential.

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