PhD Proposal: Three-dimensional kinematic model of fault networks.

Faults are a significant source of geometric and physical complexity in the subsurface. Therefore, the determination of faults parameters is very important for many applications in hydrogeology, geothermal resources, geotechnical engineering, tectonics, seismic hazard, etc. However, the available subsurface data are often insufficient to precisely characterize the geometry and the displacement of faults: limited resolution and observation gaps then need to be complemented by conceptual models to reduce uncertainty.

At metric to kilometric scale, 3D geomodeling methods generally describe faults as zero thickness surfaces. Once the geometry of these surfaces is obtained, interpolation between the surrounding observations is performed to obtain the geometric offset across the fault surface (WELLMANN & CAUMON, 2018). Whereas this method provides satisfactory results when observations are dense and accurate, it may produce inconsistent structural geometries in the presence of noise, errors, and large data gaps. Moreover, interpolation only provides the final view on the fault system and does not directly provide the displacement field, so the rock juxtaposition across a fault relies on simplifying assumptions (e.g., dip slip), the rock deformation in the flanking structures of the faults cannot be determined directly, and, more critically, the mechanical compatibility of the model cannot be assessed directly.

To address these challenges, several authors have proposed to validate the interpolated structures a posteriori using structural restoration (KERR, WHITE & BRUN, 1993; ROUBY ET AL., 2002), but the process is generally time-consuming. In seismology, the classical methods used to invert for source mechanisms are based on linear elastic assumptions which don't hold at geological time scales, and they neglect stress interactions and contacts between fractures (SEGALL & POLLARD, 1980). Alternatively, some authors have proposed parametric kinematic models to describe the near-field displacement around isolated faults (GEORGSEN ET AL., 2012; GODEFROY ET AL., 2018; GROSE ET AL., 2021; LAURENT ET AL., 2013; WALSH & WATTERSON, 1987). These models have also shown a significant value for generating training data for machine learningbased seismic interpretation (MERRIFIELD ET AL., 2022; WU ET AL., 2020). However, faults are seldom isolated, and it has been known for a long time that slip vectors show more complex behavior in areas of fault interactions, both in terms of orientation (ROBERTS, 1996) and displacement magnitude (WILLEMSE, POLLARD & AYDIN, 1996). Moreover, the existing parametric slip models do not integrate geometric constraints in the presence of branch lines. An additional difficulty comes from the interplay between fault activity and deposition, which can generate sharp variations of displacement fields orthogonally to the stratigraphy.

The overall objective of this PhD project is to advance the state of the art in the modeling of displacement associated to fault networks. The idea is to define a small number of geometric parameters that can describe the near-field discontinuous displacement of a fault network, while accounting for branch lines and interactions. After developing the numerical displacement model, the method will be tested on reference interpretations from high resolution 3D seismic data sets. After this first validation, the proposed parameterization can be considered for generating training data for AI-based seismic interpretation. In this context, an interesting question will be to measure the ability of such an extended training data base to improve the interpretation in structurally complex areas and compared to state of the art machine learning. Another pathway will be to jointly infer fault network location and slip parameters from subsurface data. This may be tested by extending existing inverse methods for isolated faults to account for interpretation picks (GODEFROY ET AL., 2018) or full waveform inversion results (RUGGIERO, CUPILLARD & CAUMON, 2024).

Advisors: Guillaume Caumon (Université de Lorraine) and Gautier Laurent (Université d'Orléans).

Starting date: From September 2025

Requirements
The candidate should hold a MSc in quantitative Earth Sciences, Geophysics, Physics, Geomechanics, Applied Mathematics or Computer Science. He/she is passionate about science and has solid scientific writing skills. An experience in computer programming and a strong command of English language are required. French language is preferable, but not necessary.

How to apply
Application files must be sent to jobs@ring-team.org before **Mai 31, 2025**, and must include:

- A cover letter,
- A CV, including contact information for two or more referees,
- A research outcome (Master thesis or paper) written by the candidate,
- An official transcript of grades.

Location
Nancy (France), a UNESCO World Heritage city with a vibrant student life and a rich cultural agenda, only 90 minutes away from Paris, Luxembourg and Strasbourg.

Working environment
The successful candidate will work in the RING Team, a pluridisciplinary and diverse group of 12-15 researchers and graduate students working at the interface of geoscience, computer science and applied mathematics. The team is part of École Nationale Supérieure de Géologie in the GeoRessources laboratory, a research lab of Université de Lorraine and CNRS. The research team is driven by passion for developing computer-based methods and theories for geological and geophysical modeling, serving the geoscience community to address scientific and natural resource management challenges.

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