Building multi-stereo Pleiades image-based DEMs and new learning tools to unravel part of the mystery of earthquakes

Keywords: Satellite image processing, digital elevation models, 3D reconstruction, machine learning, faults and earthquakes

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Context: Decades of research in earthquake sciences have yielded meager prospects for earthquake predictability: we cannot today predict the time, location and magnitude of a forthcoming earthquake. Yet important advances have been done, including the demonstration that certain intrinsic properties of the tectonic faults that produce earthquakes significantly affect their magnitude and hence their devastating potential [1]. It is thus of critical importance to properly document the properties of the faults. The latest generation of satellite-based imaging sensors (Pleiades, Sentinel, etc.) acquires big volumes of Earth surface's images with high spatial, spectral and temporal resolution (up to 50cm/pixel, 50 bands, twice per day, covering the full planet). These data offer the unprecedented opportunity to observe and to measure the faults as they appear at the Earth surface, at a level of detail and precision never achieved before. The proposed work intends to take advantage of these new satellite data to recover a specific fault property –fault rock damage, whose knowledge is needed to improve earthquake understanding and modeling.

Subject: As tectonic faults grow over time, they permanently damage the embedding crustal rocks, in the form of dense networks of secondary damage faults and fractures of various scales, spacing, orientations, etc. (Fig. 1) [1]. There exist sites over the world where the damaged rocks around faults are well exposed to observation at the ground surface. The damage faults are clearly observable, and hence measurable, for they have specific morphological and topographic signatures (Fig. 1). In this project, we firstly aim to **develop an innovative processing chain of Pléiades satellite images to recover the 3D-topography** (called digital elevation model, or DEM) at an unprecedented high resolution (0.1-0.5 m) including in the numerous shadow zones between the closely-spaced damage faults (Fig. 1b). Secondly, we intend to develop new "learning approaches" dedicated to automate the identification and the measurements of the damage faults in the high-resolution DEMs, especially their sizes, spacing, densities, and orientations. The results will feed fault and earthquake models developed in our group.

(a) (b)

Fig. 1: Example of a fault damage zone in Nevada (Google Earth map view). Damage appears as dense networks of faults and fractures, observable at ground surface and in multiple natural sub-vertical sections.

Goals:

- **Building a multi-stereo, high-resolution DEM of one damage site.** 6 to 9 Pléiades images taken from variable angles of view will be combined to produce a DEM recovering the topography everywhere including in the shadow zones. The work will be done using the MicMac software provided by IGN. Several methodological challenges are expected, such as determination of the matching points in complex fault zones and handling reconstruction in multiple shadow areas.
- **Developing stereoscopic methods to measure 3D damage faults geometries.** While the damage faults intersect the ground surface, some of them also intersect the steep flanks of the narrow corridors between the faults (Fig. 1b). Provided that the combination of the multi-stereo Pléiades images allows visualizing these intersections in the canyons' flanks, we will be able to constrain the 3D geometry (strike and dip) of the damage faults [2]. We will thus produce a 3D model of the faulted rock volume, through which actual damage fault properties will be measured.
- **Developing new machine learning approaches to automate the identification and the measurements of the damage faults in the 3D volume.** In a small area of the site, the damage faults will be identified and mapped by the tectonic experts of the team. These data will then be used as a reference to develop and train a machine learning algorithm [3], aiming to automatically recognize the damage features in the 3D Pléiades-derived topography.

What's next?: Because the work combines innovative methodological developments in remote sensing data processing, and application of these developments to critical questions in earthquake research, the internship might later evolve either into the deepening of technical skills in big data processing, or the application of remote sensing data and tools to fundamental research, especially in earthquake sciences. A PhD is possible as the continuation of this Master work.

References:

[1] Perrin, C., I. Manighetti, J.-P. Ampuero, F. Cappa, and Y. Gaudemer (2016), Location of largest earthquake slip and fast rupture controlled by along-strike change in fault structural maturity due to fault growth, *J. Geophys. Res. Solid Earth*, 121, doi:10.1002/2015JB012671.

[2] Bilotti, F., Shaw, J. H., and Brennan, P. A. (2000). Quantitative structural analysis with stereoscopic remote sensing imagery. *AAPG bulletin*, *84*(6), 727-740.

[3] Maggiori, E., Tarabalka, Y., Charpiat, G., and Alliez, P. (2016). High-Resolution Semantic Labeling with Convolutional Neural Networks, *arXiv.*

Requirements for the student:

- Good knowledge of image processing, optimization and algorithms
- Good coding skills
- Fluency in English
- Interest in natural faults and earthquakes