ÉCOLE DOCTORALE
SCIENCES DE LA TERRE ET DE L'ENVIRONNEMENT
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Subject title: **Investigation of the processes behind seismic swarms in the archipelago of Les Saintes (Guadeloupe, Lesser Antilles)**

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On November 21, 2004, a magnitude 6.3 intraplate earthquake struck offshore, approximately 10 km south of the Les Saintes archipelago in Guadeloupe (Lesser Antilles, Feuillet et al., 2011). This seismic event, reaching intensity VIII in Les Saintes, resulted in significant damage and one fatality in Guadeloupe (Bazin et al., 2010).

Following the main shock, aftershock activity was notably intense, with over 30,000 recorded aftershocks in the subsequent two years. To map the activated region, six ocean bottom seismometers (OBS) were deployed between 25 and 66 days after the main event (Bazin et al., 2010). Analysis of the aftershock distribution, both spatially and in depth, revealed the activation of a northeast-dipping fault, oriented northwest to southeast, identified as the Roseau fault. This fault traverses beneath the ancient volcanic structure of the Les Saintes archipelago.

Remarkably, aftershock activity has persisted for almost two decades, continuously monitored by an increasingly advanced network of on-land permanent stations (Massin et al., 2021), and more recently, by a permanent seafloor station (Bernard et al., 2024).

While the initial aftershock sequence clearly delineated the Roseau fault plane, along with some associated antithetic structures (Bazin et al., 2010), the subsequent 20 years have seen a more scattered distribution of aftershocks. A major cluster of seismicity has emerged beneath the Les Saintes plateau, marking the northern extent of the aftershock activity, while a smaller cluster, with fewer events, lies to the south of the Roseau fault, indicating its southernmost termination.

An initial attempt to relocate the 20 years of seismic activity in the Les Saintes region, undertaken as part of an M2 internship conducted in 2024 at IPGP, did not yield definitive evidence of fault structures associated with these events. The seismicity appears diffuse, suggesting possible pore pressure perturbations around the Roseau fault. Interestingly, the two diffuse clusters correspond to the relatively younger volcanic structures situated between the Les Saintes plateau and Dominica, as identified by Henri et al. (2022), with estimated ages of 0.9 and 0.3 million years, respectively.

The main aim of this thesis is to investigate the hypothesis regarding the driving force behind the seismic activity in the Les Saintes region over the past two decades. Specifically, it seeks to determine whether this activity has been influenced by pore pressure perturbations associated with volcanic fluid circulation, potentially triggered by the 2004 main rupture event.

Studies on seismicity induced by the injection of pressurized fluids reveal a pattern of diffuse seismic activity surrounding the fluid injection site, often propagating along pre-existing fault lines. In natural settings, such as Colfiorito (Miller et al., 2004), normal faults act as conduits facilitating the escape of fluids stored in reservoirs. This process alters fault behavior, disturbs surrounding pore pressure, and triggers diffuse seismicity in the vicinity of the fault. In the Les Saintes context, the Roseau fault and/or secondary faults within the normal fault system emerge as plausible conduits for fluid flow. Therefore, ensuring the accuracy of seismicity location becomes a crucial aspect before any interpretation can be made.

Within the framework of this thesis, the initial step involves refining the seismicity location. To achieve this, we will revisit the continuous waveform database from on-land stations, recently converted to a modern seismic format. Utilizing cutting-edge tools for automated phase picking (Phasenet: Zhu and Beroza, 2018) and association (Gamma: Zhu et al., 2022), we aim to generate an enhanced catalog spanning 20 years of Les Saintes seismic activity. Subsequently, events will undergo relocation using a high-precision earthquake location code, incorporating source-specific station terms and inter-event waveform similarity (NLL-SST-Coherence, Lomax and Savvaidis, 2021). The efficiency of these methodologies was demonstrated during an M2 internship conducted at IPGP in 2024, where post-seismic OBS data from Les Saintes was reevaluated.

The subsequent phase of our investigation involves determining the velocity structure on the scale of the Roseau fault extension by means of a differential tomography analysis, which will benefit from the above double difference relocation. In fluid-saturated rock formations, the compressibility of fluids significantly impacts the velocity of P-waves (Vp) and S-waves (Vs). Formations containing liquids exhibit elevated Vp/Vs ratios, whereas those containing gas demonstrate lower Vp/Vs ratios (e.g., Lesage et al., 2018).
An additional piece of information could come from the analysis of the Qp and Qs attenuation factors from the inversion of seismic spectra.

Another facet of the project involves investigating multiplets and repeating earthquakes, which serve as indicators of the ongoing forcing process, whether pore pressure or fault creep. To identify these phenomena, we will employ the Requake code developed by Satriano (2024) for detecting repeating earthquakes. Subsequently, we will use the models proposed by Dublanchet et al. (2015) and Danré et al. (2022) to interpret the results, aiming to establish connections between the location and potential migration of seismic swarms with the underlying forcing mechanism. The inferred transient sources of creep, if any, will be used to calculate the induced strain and tilt at the surface, in particular near the southern edge of Terre-de-Bas island (where the epicenters of the recent multiplets are located). This will allow defining the optimal locations of strain meter sites for envisioned future instrumentation projects. Such installation would indeed provide essential information to decipher the processes at work during the seismic swarms.

We will seek out recurrent multiplet families within seismicity spanning the last 20 years to identify the structures/faults where they manifest. In August 2019, the LB seismometer at the Terre de Bas station was installed in a borehole, which prevents us from tracking the temporal evolution of multiplet families. As part of the thesis, we plan to deploy a surface LB seismometer at the same location to rediscover the enduring families. The recurrence of multiplet families implies the existence of enduring structures, shedding light on the overall behavior of the region.

The thesis will be carried out within the Seismology Group at IPGP, under the guidance of Pascal Bernard and co-supervised by Marie-Paule Bouin. This endeavor will be enriched by collaborations with fellow group members, including Claudio Satriano, as well as researchers from the Marine Geoscience and Volcanology groups. Throughout the duration of the thesis, efforts will be made to establish national and international collaborations, tailored to the specific areas requiring further development.

References:

Bazin *et al.* (2010). The 2004–2005 Les Saintes (French West Indies) seismic aftershock sequence observed with ocean bottom seismometers. *Tectonophysics* 10.1016/j.tecto.2010.04.005

Bernard *et al.* (2024). First installation of an optical ocean bottom seismometer, cabled offshore Les Saintes, Lesser Antilles. Accepted in *Seism. Res. Lett.*

Danré *et al.* (2022). Prevalence of Aseismic Slip Linking Fluid Injection to Natural and Anthropogenic Seismic Swarms. *J. Geophys. Res.: Solid Earth.* 10.1029/2022jb025571

Dublanchet *et al.* (2015). Inferring fault mechanical conditions from the source parameters of a complex microseismic multiplet in the Corinth rift, Greece. *J. Geophys. Res.: Solid Earth* 10.1002/2015jb012259

Feuillet *et al.* (2011). The Mw 6.3, November 21, 2004, Les Saintes earthquake (Guadeloupe): Tectonic setting, slip model and static stress changes. *J. Geophys. Res.* 10.1029/2011jb008310

Henri *et al.* (2022). K-Ar Geochronology and geochemistry of underwater lava samples from the Subsaintes cruise offshore Les Saintes (Guadeloupe): Insights for the Lesser Antilles arc magmatism. *Marine Geology.* 10.1016/j.margeo.2022.106862

Lesage *et al.* (2018). A generic model for the shallow velocity structure of volcanoes. *J. Volcanol. Geotherm. Res.* 10.1016/j.jvolgeores.2018.03.003

Lomax & Savvaidis (2021). High-Precision Earthquake Location Using Source-Specific Station Terms and Inter-Event Waveform Similarity. *J. Geophys. Res.: Solid Earth.* 10.1029/2021jb023190

Massin *et al.* (2022). Automatic picking and probabilistic location for earthquake assessment in the Lesser Antilles subduction zone (1972–2012). *C. R. Géosci.* 10.5802/crgeos.81

Miller *et al.* (2004). Aftershocks driven by a high-pressure CO2 source at depth. *Nature.* 10.1038/nature02251

Satriano, C. (2024). Requake – Repeating earthquakes search and analysis. 10.5281/zenodo.10832204

Zhu & Beroza (2018). PhaseNet: A Deep-Neural-Network-Based Seismic Arrival Time Picking Method. *Geophys. J. Int.* 10.1093/gji/ggy423

Zhu *et al.* (2022). Earthquake Phase Association Using a Bayesian Gaussian Mixture Model. *J. Geophys. Res.: Solid Earth.* 10.1029/2021jb023249