ÉCOLE DOCTORALE
SCIENCES DE LA TERRE ET DE L'ENVIRONNEMENT ET PHYSIQUE DE L'UNIVERS, PARIS

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Titre du sujet : Towards understanding magma processes at Mt Merapi Volcano.

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Volcanoes are highly complex structures where solid, liquid and gas phases coexist inside the edifice. It has been estimated that about 800 million people live within a 100 km radius from an active volcano (Brown et al., 2015). However, volcanoes remain poorly understood especially due to their great variability in types and along time. Two different approaches are taken into account in volcanic surveillance : 1) short-term forecasting which is used once volcanic unrest is observed and consists in interpreting patterns, geophysical monitoring data observation. 2) long-term analysis, based on statistical inferences and characterization from a catalog. Both can lead to different but important decisions such as emergency planning and eventual evacuation on the short and long-term, but also land-use and management, development of urbanization and resilience improvement (Sheldrake et al., 2017).

Indonesia is one of the most exposed countries to volcanic hazards, and Mount Merapi volcano is considered as one of the most dangerous volcanoes of Indonesia due to its densely populated surroundings and its high levels of eruptive activity (Budi-Santoso et al., 2013; Jousset et al., 2013). Notably, the 2010 Merapi eruption of VEI 4 was characterized by a dome collapse and the summit destruction causing large Pyroclastic Density Currents (PDC). This eruption was of a magnitude unknown since 1872 and marked a change in the eruption style of the volcano. This event has led to the emergency evacuation of over 400 000 people (Jenkins et al., 2013; Mei et al., 2016).

Mt Merapi last eruption started in 2018 and is still on going today. Since 2018 a new dome is growing in the summit from the scars of the 2010 eruption, in addition to the remaining dome which is still active. The presence of 2 domes poses the issue of the increase of Mt Merapi eruption radius and eruption directions (Kelfoun et al., 2021).
The prediction of PDC characteristics resulting from lava dome collapse are essential for hazard assessment and risk evaluation. However, major questions still remains unanswered. Is the dome collapse purely gravitational and caused by over-steepening of the dome ? Is the pressure of volcanic gases responsible for dome destruction ? What are the effects of the structure of the dome and its substratum ? (Kelfoun et al., 2021; Voight & Elsworth, 2000)

Seismic waveform and spectral analysis enable to characterize and classify volcanic seismicity in 8 major families of events (Chouet & Matoza, 2013; McNutt, 2002). Each family testifies to a particular physical phenomenon happening in the volcanic edifice which can be used to forecast eruption based on the occurrence of seismic classes in the time line and space (R. White & McCausland, 2016; R. A. White & McCausland, 2019). Interaction between solid, liquid and gas, fluid migration, hydraulic fracking, hydro-shearing and architectural complexity of the inner structure generate characteristic seismic signals that allow to relate them with their sources. The great variability of signatures within seismic classes and changes of intra classes properties along time for a given volcano poses the challenge of systemic source mechanism identification as well as the determination of propagation effects through volcanic medium.

VLP events are characterized by frequencies below 0.2 Hz and are related with inertial fluid mouvements (magma, gas) within the volcanic system and their occurrences has been correlated with gas emissions (Konstantinou, 2023). LP events are characterize by a frequency content from 0.2 to 5 Hz. This type of events is generally associated with resonance in fluid filled cavities. However some studies proposed other source mechanisms for shallow LP seismicity as the abrupt mass shift of solidified domes, conduit magma or magma pads (Johnson et al., 2008) and slow-rupture earthquakes (Bean et al., 2013). Furthermore, the GNSS might be sensitive to magma overpressure in the shallow or deep plumbing system, and viscous friction on the conduit wall (Beauducel et al., 2000).

During this PhD we propose seismic analysis to characterize the long term behavior of Mt Merapi volcano using seismic data collected since 2013. The PhD objectives are :

1) Spatial identification of magma path and temporal link with emissions. Can we estimate the volume of magma emitted using seismicity ?
2) Mechanical behavior of the structure submitted to magmatic intrusion. Is the deformation observed linked with gravitational effects and/or with intrusion ? Can seismicity enable to quantify the partition of each factor in the deformation processes ?

In a first part, in order to retrieve the source processes from structural changes and propagation effects, the PhD aims to study structural changes and create a new velocity model for the volcano. This will be based on previous results of a tomography experiment (2013-2015) and GNSS baselines obtained since 2013 (Ramdhan et al., 2019; Widiyantoro et al., 2018). It will be updated to fit post 2018 seismicity and observed deformation patterns, as a new eruptive phase started at period an is still on going today.

In a second part, the long term evolution of seismicity and signal characteristics analysis is aimed to distinguish volcanic activity from external forcing, such as climatic effects in this tropical context. The seismicity will then be characterized spatially and temporarily by relocation to identify magma path, related source mechanisms and their occurrences with respect to emissions. The combined GNSS and seismic analysis should enable to determine seasonal processes from magma intrusions and gravitational effects, as well as enabling magma ascent and dynamics within the edifice with resect to time.

Finally, this PhD will focus on Very Long Period (VLP) and Long Period (LP) seismicity. Both LP and VLP were identified during the 2010 eruption of Mt Merapi. Large variations were observed in the LP complex frequency content and interpreted as resulting from a resonating crack system and a change in the resonance pattern with time. 3 main hypothesis remains to explain the origin of such seismic signals : a change in the density ratio of fluid to solid, a change in the geometry of a single resonator, or excitation of different resonators. According to the evolution of LP cluster hypocenters, and VT earthquake migration the excitation of different resonators seems the most plausible, as changes in their complex frequencies along eruption time were thought to be related by magma (Jousset et al., 2013).

In the light of these results, the characterization of VLP and LP events, temporarily and spatially, and the analysis of intra classes properties evolutions is aimed to study the partition of sources mechanisms related to fluid movements and path effects related to deformation. GNSS complementary analysis will enable the determination of deformation source positions trough time and space, as well as helping to determine the partition between attenuated, due to path effects and deformation in the edifice, and fluid migration induced low frequency seismicity (Bean et al., 2013; Beauducel et al., 2000).

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