Tracking magma movements in the Virunga volcanic province using seismic Amplitude Ratio Analysis (SARA)

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1. Abstract

Volcanic eruptions are often characterized by the emission of magma at the surface. Prior to the extrusion, magma rises or moves laterally in the crust releasing seismic energy. These movements can be tracked using seismic waves recorded by a network of seismometers deployed around the studied volcano. A new methodology called the Seismic Amplitude Ratio Analysis (SARA) has been designed to detect and locate magma migrations in the subsurface at volcano observatories and for research purposes (Taisne et al. 2011). By analyzing the evolution of seismic amplitude ratios recorded at different pairs of stations corrected for site effects, the location of magma can be assessed without picking any earthquake; the most traditional way to detect melt movements.

This study tests the potential of this technique using a seismic network, the KivuNet, deployed in the Virunga Volcanic Province. The Virunga Volcanic Province is located in eastern DRC in a transition zone between Lake Eduard and Lake Kivu where the western branch of the East African Rift changes direction from N-S to NNE-SSW. Two out of the eight volcanoes, i.e., Nyamulagira and Nyiragongo, are currently active and considered as the most active volcanoes in Africa. The presence of the Nyiragongo volcano near the cities of Goma and Gisenyi makes this area with its complex socio-political context among the most vulnerable areas to eruption risk.

Given the high risk in the area, the seismic surveillance in the Virunga region started in the 1960s, but an operational network only emerged after the 2002 Nyiragongo eruption. Most of the seismic studies(Lukaya et al. 1992; Wafula et al. 1992; Mavonga et al. 2006, 2010; Tuluka 2010) have been dedicated to the location of long-period (LP) and volcano-tectonic (VT) events recorded during earthquake swarms preceding eruptions using classical methods. However, these methods are not efficient in the presence of emergent volcanic signals, especially with small seismic networks, resulting in large uncertainties with LP locations. A new network has been developed in the area since 2013, which permitted new initiatives to track the magmatic activity with seismic approaches. Recent efforts successfully located volcanic tremor using cross correlation functions(Barrière et al. 2017) .

In our study we apply the SARA method that successfully tracked magma migration at the Piton de la Fournaise (La Réunion), Tolbachik (Russia) and Bardarbunga (Iceland) volcanoes. The advantage of this technique compared to the approach developed by Barrière et al. (2017) concerns it better temporal resolution that would offer the possibility to automatically locate volcanic tremor thereby allowing to locate magma in real-time, possibly before an eruption occurs.

We used more than 3 years of high-quality seismic data recorded by ~15 telemetered seismic stations of the broadband network KivuSNet. The 0.3-1 Hz frequency band was selected because it corresponds to coherent volcanic tremor sources from the Nyiragongo and Nyamulagira volcanoes, and is thus representative of the magmatic activity in the region(Barrière et al. 2017). To constrain magmatic intrusions, the 3D location requires a preliminary estimate of site amplification factors. The MSNoise software(Lecocq et al. 2014) was used to process the seismic data and calculate amplitude ratios. We then validate the methodology by comparing our seismic amplitude ratio and locations with tremor locations using the cross-correlation approach, earthquake activity, SO_2 emissions.

Preliminary resultants show good correlation of main observations of magmatic evolution during the period from October 2015 to February 2017 made by Julien and it suggests good ability of the SARA method to track the magmatic intrusions in the VVP.

2. References

Barrière J, Oth A, Theys N, et al (2017) Long-term monitoring of long-period seismicity and space-based SO 2 observations at African lava lake volcanoes Nyiragongo and Nyamulagira (DR Congo). Geophys Res Lett 44:6020–6029. doi: 10.1002/2017GL073348

Lecocq T, Caudron C, Brenguier F (2014) MSNoise, a Python Package for Monitoring Seismic Velocity Changes Using Ambient Seismic Noise. Seismol Res Lett 85:715–726. doi: 10.1785/0220130073

Lukaya N, Ciraba M, Mavonga T, Wafula M (1992) Main pattern of waveforms observed in the Virunga volcai zone, Western rift valley of Africa. Tectonophysics 209:261–265. doi: 10.1016/0040-1951(92)90031-Z

Mavonga T, Kavotha SK, Lukaya N, et al (2006) Seismic activity prior to the May 8, 2004 eruption of volcano Nyamuragira, Western Rift Valley of Africa. J Volcanol Geotherm Res 158:355–360. doi: 10.1016/j.jvolgeores.2006.06.021

Mavonga T, Zana N, Durrheim RJ (2010) Studies of crustal structure, seismic precursors to volcanic eruptions and earthquake hazard in the eastern provinces of the Democratic Republic of Congo. doi: 10.1016/j.jafrearsci.2010.08.008

Taisne B, Brenguier F, Shapiro NM, Ferrazzini V (2011) Imaging the dynamics of magma propagation using radiated seismic intensity. Geophys Res Lett 38:2–6. doi: 10.1029/2010GL046068

Tuluka GM (2010) Crustal structure beneath two seismic broadband stations revealed from teleseismic P-wave receiver function analysis in the Virunga volcanic area, Western Rift Valley of Africa. doi: 10.1016/j.jafrearsci.2009.11.003

Wafula M, Zana N, Mavonga T, Sassa M (1992) Recent Seismicity of the Virunga volcanic zone, Western rift, Zaire. Tectonophysics 209:259–260. doi: 10.1016/0040-1951(92)90030-A