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# Spatial variation of volcanic rock geochemistry in the Virunga Volcanic Province: Statistical analysis of an integrated database

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ABSTRACT

We present an integrated, spatially-explicit database of existing geochemical major-element analyses available from (post-) colonial scientific reports, PhD Theses and international publications for the Virunga Volcanic Province, located in the western branch of the East African Rift System. This volcanic province is characterised by alkaline volcanism, including silica-undersaturated, alkaline and potassic lavas. The database contains a total of 908 geochemical analyses of eruptive rocks for the entire volcanic province with a localisation for most samples. A preliminary analysis of the overall consistency of the database, using statistical techniques on sets of geochemical analyses with contrasted analytical methods or dates, demonstrates that the database is consistent. We applied a principal component analysis and cluster analysis on whole-rock major element compositions included in the database to study the spatial variation of the chemical composition of eruptive products in the Virunga Volcanic Province. These statistical analyses identify spatially distributed clusters of eruptive products. The known geochemical contrasts are highlighted by the spatial analysis, such as the unique geochemical signature of Nyiragongo lavas compared to other Virunga lavas, the geochemical heterogeneity of the Bulengo area, and the trachyte flows of Karisimbi volcano. Most importantly, we identified separate clusters of eruptive products which originate from primitive magmatic sources. These lavas of primitive composition are preferentially located along NE-SW inherited rift structures, often at distance from the central Virunga volcanoes. Our results illustrate the relevance of a spatial analysis on integrated geochemical data for a volcanic province, as a complement to classical petrological investigations. This approach indeed helps to characterise geochemical variations within a complex of magmatic systems and to identify specific petrologic and geochemical investigations that should be tackled within a study area.



## 1. Introduction

The Virunga Volcanic Province (VVP) is located in the western branch of the East African Rift System (EARS; Ebinger and Furman, 2003), at the intersection between the Democratic Republic of Congo, Rwanda and Uganda. It comprises eight main volcanoes, including two active ones, and numerous pyroclastic cones (Fig. 1). Magmatism in the VVP is characterised by silica-undersaturated, alkaline and potassic volcanism, with marked geochemical variations across the volcanic field (e.g., Aoki et al., 1985; Toscani et al., 1990; Platz et al., 2004; Chakrabarti et al., 2009).

Existing petrological investigations in the VVP documented the mineralogy, petrology and geochemistry of eruptive products, generally focusing on a single volcano or sub-field of the VVP (e.g., Nyamulagira volcano: Pouclet, 1976; Aoki et al., 1985; Nyiragongo volcano: Demant et al., 1994; Capaccioni et al., 2003; Platz et al., 2004; Chakrabarti et al., 2009; Karisimbi volcano: De Mulder, 1985). Different parts of the VVP are thus represented in an uneven manner in the existing analytical studies of the eruptive products, and less attention has been given to documenting the older eastern part of the VVP and, consequently, the geochemical variations across the entire volcanic province. Moreover, fewer

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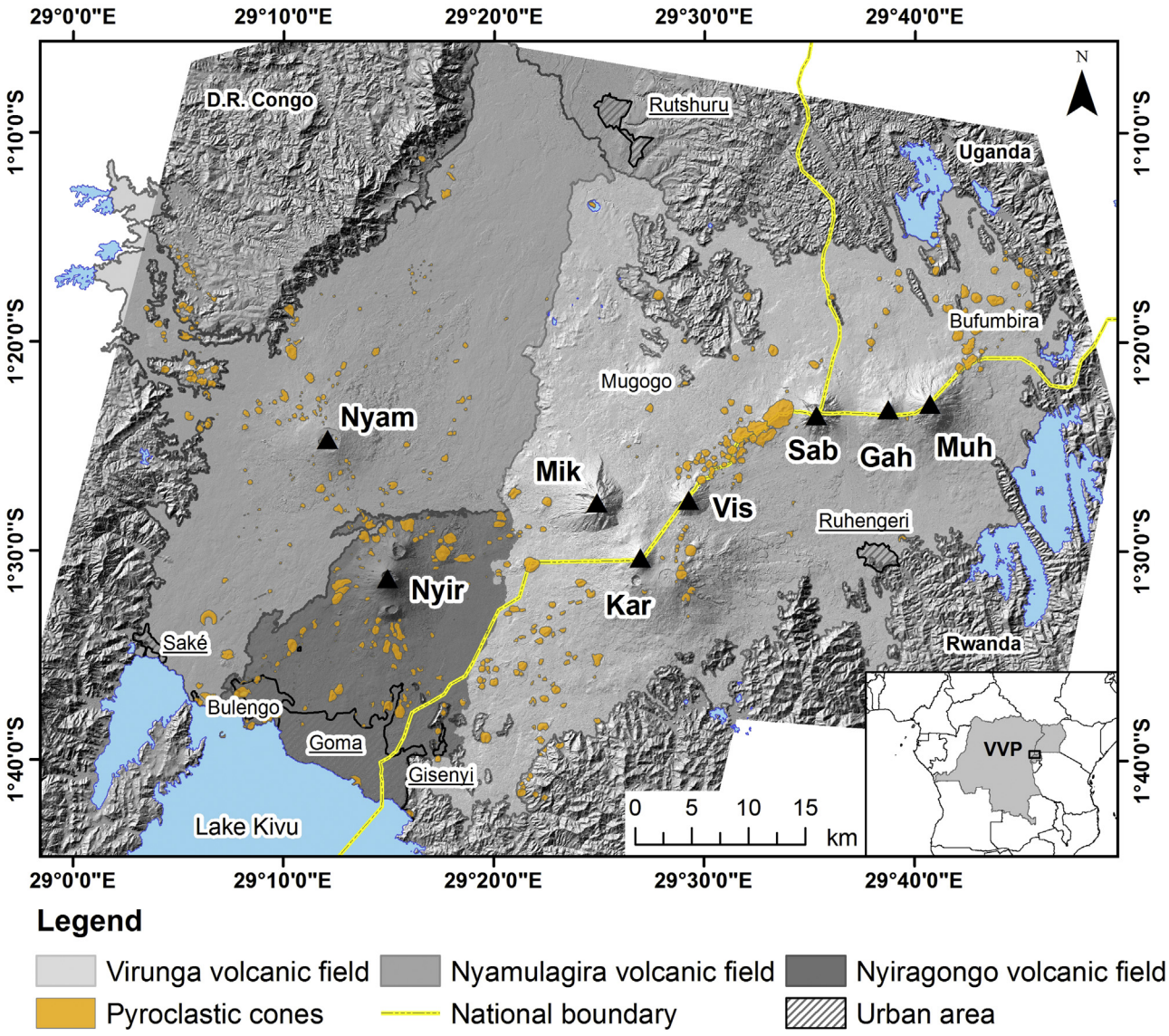


**Fig. 1.** Map of the Virunga Volcanic Province showing the main volcanic edifices (black triangles) and the >500 pyroclastic cones (yellow polygons). Nyam = Nyamulagira; Nyir = Nyiragongo; Mik = Mikeno; Kar = Karisimbi; Vis = Visoke; Sab = Sabinyo; Gah = Gahinga; Muh = Muhavura. Background: TanDEM-X based hillshade image (Albino et al., 2015).

studies were conducted over the last two decades (e.g., Capaccioni et al., 2003; Platz et al., 2004; Chakrabarti et al., 2009) due to the continuing social and political instability that affects the region since the early 1990s.

As a consequence, there is no existing petrological study of the VVP providing a comprehensive vision of geochemical variations through space. This study attempts to partly solve this, by presenting a new integrated database of spatially explicit whole-rock major element geochemical compositions of Virunga volcanic rock samples available in the literature. As a preliminary analysis of the database, we present a spatio-statistical analysis of volcanic whole-rock geochemistry variation throughout the VVP. Our original approach, which is based on principal component analysis and cluster analysis, aims (i) to highlight the major element compositions already available for the VVP by integrating them into one single database; and (ii) to identify the spatial extent and range of geochemical compositions of eruptive products in the VVP, with the goal to extrapolate patterns previously recognized in specific sample subsets to the entire province.

## 2. Main characteristics of the Virunga Volcanic Province

Among the eight main edifices of the VVP, Nyiragongo and Nyamulagira volcanoes are currently the most active volcanoes of Africa (Wright et al., 2015). Nyamulagira volcano experienced at least 42 eruptions since 1882 and contains a lava lake that appeared in November 2014 (Smets et al., 2014a, 2015). The eruptive activity of Nyiragongo volcano over the last 150 years is characterised by intracrater activity, corresponding to the presence of a persistent lava lake (1928–1977, 2002-present; Sahama and Meyer, 1958; Durieux, 2003) or lava fountaining activity creating an ephemeral lava lake (1982, 1994–1995 eruptions; Krafft and Krafft, 1983; Tazieff, 1984; Durieux, 2003; Komorowski et al., 2003). This intracrater activity was interrupted by two flank eruptions, in 1977 and 2002 (Tazieff, 1977; Komorowski et al., 2003). The intense volcanic activity of Nyamulagira and Nyiragongo volcanoes ensured an