International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Carbon Dioxide Behaviour in the Fractures Two Years before the May 22nd 2021 Nyiragongo Volcano Eruption

Bahati Rusimbuka Marcel[1,*,A], Birisawa Ntamuhanga[1], Safari Habari[1], Muhambikwa Kasiwa[2], Ngangu Bonheur[3], Maombi Nzamu[3], Sadiki Tumaini[4], Mirimo Munpfano[1], Habamungu Balikumwami[1]

[1]Department of Geochemistry and Environment, Goma Volcano Observatory, Goma, DR Congo
[2]Provincial Inspection of Agriculture, Service National des Semences du Nord-Kivu, Goma, DR Congo
[3]Department of Geodesy and Deformation, Goma Volcano Observatory, Goma, DR Congo
[4]Departement of Seismology, Goma Volcano Observatory, Goma, DR Congo
[a]Public Health Researcher, Goma, DR Congo
*Corresponding Author E-mail: rusimbuka3@gmail.com

DOI: https://doi.org/10.55248/gengpi.2022.3.2.16

ABSTRACT

Nyiragongo, remains one of the most active volcanoes in the Virunga chain. It is feared for its permanent activity. It has fissural and fracturing characteristics. The carbon dioxide released by Nyiragongo is regularly monitored on the southern flank of the volcano. Five sampling points were taken into consideration during our study. The data collected over a two-year period (since 2019) prior to the eruption of 22 May 2021 show a certain change in the monitoring curves. All the sampling points included in this work show an increase in carbon dioxide concentration in October 2020, seven (7) months before the event. This rise in carbon dioxide concentration in the southern fractures of Nyiragongo reflects in some way the degree of (intense) activity in the magma reservoir, which also induced a magmatic rise. Of the five points monitored, four were found to be hyperascending, even increasing by more than twice the concentration usually measured; all the Buragura sites showed this difference.

Key words: Carbon Dioxide Behaviour, Fractures, Nyiragongo Volcano, Nyiragongo Eruption

1. Introduction

Nyiragongo is a stratovolcano of the Great Rift Valley located in North Kivu Province, Democratic Republic of Congo. It is located in the Virunga mountain chain at about 20 km in the north of the Goma city and Lake Kivu and west of the border with Rwanda.

Spatial and temporal variations in soil CO_2 fluxes (f CO_2) have been measured in many volcanic and hydrothermal systems worldwide [Farrar et al., 1995; Koepenick et al., 1996; Salazar et al., 2001; Lewicki et al., 2003] and used as a tool for volcano and seismotectonic monitoring, geothermal exploration, delineation of fault and fracture zones, and estimation of the contribution of CO_2 from volcanic and hydrothermal sources to the global carbon cycle.

Active volcanoes continuously but variably emit CO_2 through diffuse emissions on their flanks, exposing the overlying ecosystems to elevated levels of atmosphericCO_2.[Bogue R. R., et al., 2019.]

Magma mixing is a ubiquitous process in many arcrelated volcanic systems; it brings together compositionally and physically dissimilar magmas whose interaction can provide a trigger for eruption. (Sparks et al., 1977; Eichelberger, 1980)

Volcanic unrest is the manifestation of complex sub-surface processes leading to detectable signals at the ground surface. Processes such as magmamigration and emplacement, tectonic and hydrothermal activity can trigger seismicity, ground deformation, thermal variations and changes in the potential fields around a volcano. Seismicity and ground deformation may be induced by brittle failure of surrounding rocks due to the pressure increase accompanying the replenishment of magma reservoirs and the exsolution of a gas phase, a process regarded as a key trigger for volcanic eruptions. (Murphy et al., 1998).

Magmatic degassing is an exciting field of investigation to develop reliable models for forecasting volcanic activity. [Rizzo et al., 2009]

The broad flanks of active volcanoes experience diffuse emissions of excess CO_2 because the underlying active magma bodies continuously release gas, dominated by CO_2 transported to the surface along fault lines[Chiodini et al., 1998; Dietrich et al., 2016; Farrar et al., 1995]

This process has frequently been studied to understand the dynamics of active magma chambers and to assess potential volcanic hazards [Chiodini et al., 1998; Sorey et al., 1998]. These emissions are released through faults and fractures on the flanks of the volcano [Burton et al., 2013; Pérez et al., 2011; Williams-Jones et al., 2000].

Some of these faults tap into shallow acid hydrothermal aquifers, but by the time these gases reach the surface of most forested volcanoes, soluble and reactive volcanic gas species (e.g., SO_2, HF, HCl, and H_2S) have been scrubbed out in the deep subsurface, leading to a diffusely emanated gas mix of predominantly CO_2 with minor amounts of hydrogen, helium, and water vapor reaching the surface. [Symonds et al., 2001]

Among major volatiles emitted from volcanoes, CO_2 has a low solubility in melts and is released at great depth strongly contributing to the deep carbon cycle.[G. Boudoire, et al., 2018]

Volcanic CO_2 has no ^{14}C and a ^{13}C signature typically ranging from around -7‰ to -1 ‰, which is distinct from typical vegetation and noticeably enriched in ^{13}C compared to typical atmospheric values [Mason et al., 2017].

The isotope composition of carbon (^{13}C) of CO_2 is also an important tracer of magmatic degassing, because it fractionates during this process moving towards lower values. [Shaw et al., 2004)]

A series of studies at Mt. Etna in Italy and Mt. Nyiragongo in the Democratic Republic of the Congo found linear anomalies in the NDVI (normalized difference vegetation index), a measure of vegetation greenness. One to two years after the appearance of the NDVI anomalies, flank eruptions occurred directly along the line of the anomaly, indicating a plant response to the volcano's pre-eruptive state which may be due to increased CO_2 emissions in the build up to the eruption [Houlié et al., 2006].

Due to the hazard associated with eruptions and the value of volcanic gas monitoring to aid in eruption forecasting, much of our knowledge about the degassing of volcanic systems comes from active volcanoes, and typically during periods of unrest. At less active and dormant (i.e. inactive) volcanoes, magmatic emissions of CO_2 are less obvious. CO_2 emissions are typically highest in thermal areas where gases are emitted through small fumaroles, soils, and fractures as diffuse degassing and through hot and cold springs. [Werner, C., et al., 2019]

2. Study environment, data collection, Materials and method

Data collection, Materials and method

A large fracture leaves the central crater of Nyiragongo towards Lake Kivu. This fracture crosses both the territory of Nyiragongo and the city of Goma. Data about the concentration of carbon dioxide (CO_2) are collected on this main fracture. The measurements are carried out in the Nyiragongo territory. For this purpose, measurement sites have been selected. In this paper, we present the data collected at the Bugarura and Munigi sites.

The concentration of CO_2 is collected using the GA5000 gasometer. During measurement, a metal probe is inserted into the ground at the fracture (sampling site), this probe is connected to the GA5000, switched on, by a kit (plastic pipe). When the equipment is already in place, the pumping (suction) of air from the medium (soil) is activated; when the value (concentration) is stabilized, we record the data.

The recorded data are entered into a database for analysis and interpretation. The data were analyzed in Microsoft Excel.

Study environment,

The Nyiragongo Territory is a deconcentrated administrative entity in the east of the North Kivu province in the Democratic Republic of Congo. It has only one chiefdom led by the Mwami and is divided into 7 groups of 58 villages. Its chief town is Kibumba. With an estimated population of some 145,748 inhabitants by 2016 [Bureau de la chefferie de Bukumu, 2016] and an area of 163 km^2.

It is limited:

- In the North: The chiefdom of BWISHA in the territory of Rutshuru;
- In the South: The commune of Karisimbi in the city of Goma;
- In the East: The Rwandan Republic;
- To the West: The free zone of the Virunga National Park which separates it from the chiefdom of Bahunde in Masisi Territory. [Faustin Safari Habari, et al., 2021]

3. Result and Discussion

3.1. Evolution of carbon dioxide at the Munigi site

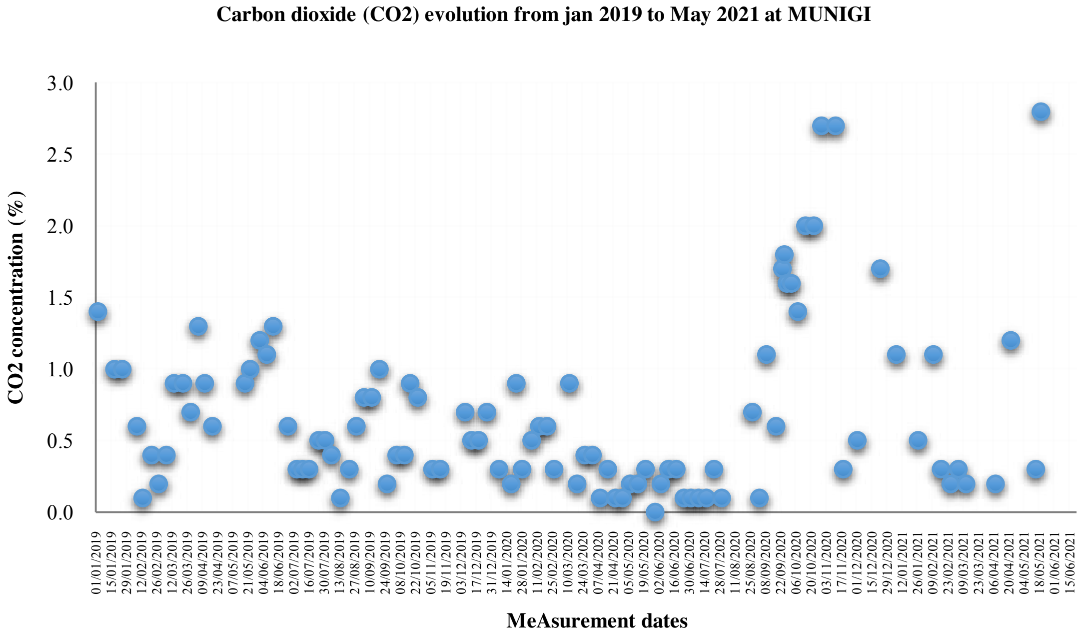

Fig.1.: Carbon dioxide measurement at Munigi site from january 2019 to may 2021

It is observed that at the Munigi site, the concentration of carbon dioxide evolves in a sawtooth pattern. A slight upward trend is visible over the entire study period; period from January 03, 2019 to May 20, 2021. The concentration of CO_2 is relatively lower at Munigi.

These data show a decreasing trend throughout 2019 until August 2020. During this period, the CO_2 average concentration at Munigi was 0.5%. A positive deformation is noticed from the month of September 2020. From the September 2020, this average rose to 1.2%.

3.2. Evolution of carbon dioxide on Bugarura sites

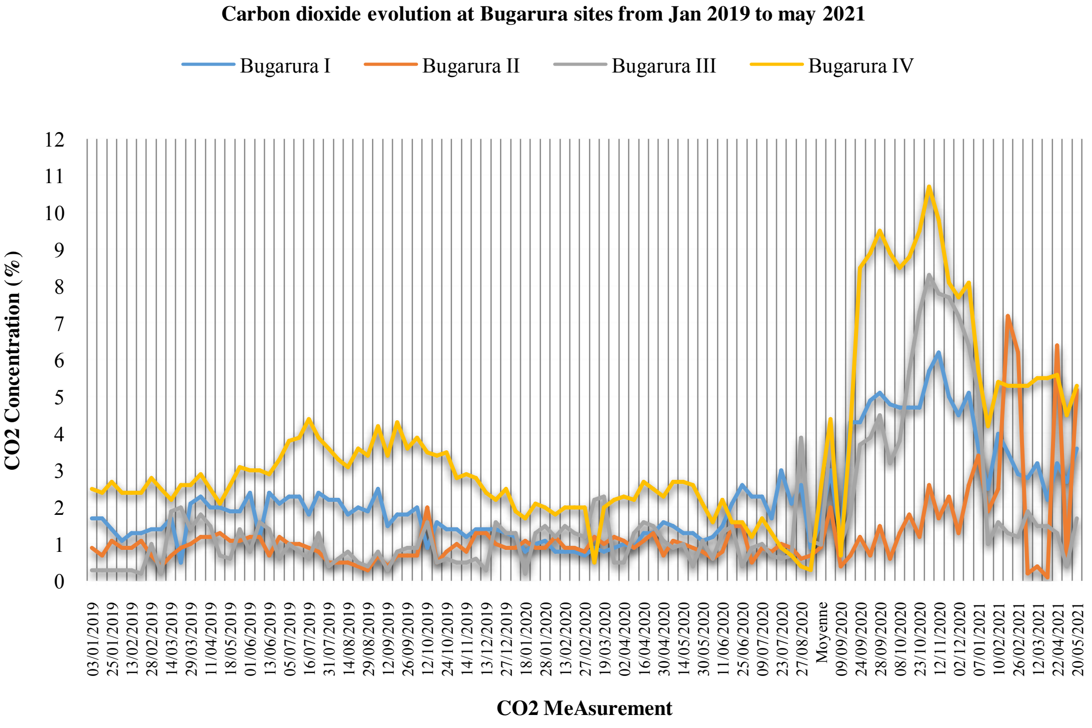

Fig.2.: Carbon dioxide measurement at Bugarura points from january 2019 to may 2021

The Bugarura sites are characterized by nearly constant carbon dioxide concentrations not exceeding 4.4% during the period from January 2019 to August 2020. Elevations in carbon dioxide concentration were noticed starting in September 2020. All the sampling points in Bugarura each showed an elevation in carbon dioxide concentration from the September 2020. Bugarura1,2,3 and 4 whose average before September 2020 was 1.6%, 0.9%, 1% and 2.5% respectively saw their average concentration rise from September onwards to 4%, 2.2%, 3.6% and 6.8% respectively. The peak of 10.7% carbon dioxide was observed in October 2020.

During this study, it was found that the carbon dioxide concentration average was between 0.7% and 3.6% at the different measurement points. These results are close to those found in a study in Clermont-Ferrand which states that "the average CO2 concentration (2.5%) is in line with what can be expected from a soil in a temperate climate" [Lary, Louis et al., 2016].

Conclusion

Nyiragongo, a strato-volcano, is fractured/cracked CO2, a heavy gas, diffuses through the fractures. The monitoring of the carbon dioxide concentration is done on the fracture leaving the summit of Nyiragongo and heading towards Lake Kivu through the city of Goma. The measurements are taken in the Nyiragongo territory, specifically in the villages of Bugarura and Munigi.

The concentration of CO_2 is relatively lower at Munigi. Data show a decreasing trend throughout 2019 until August 2020. During this period, the CO_2 average concentration at Munigi was 0.5%. A CO2 elevation is noticed from the month of September 2020. From the September 2020, this average reached 1.2%.

The Bugarura sites are characterized by nearly constant carbon dioxide concentrations not exceeding 4.4% during the period from January 2019 to August 2020. Elevations in carbon dioxide concentration were noticed starting in September 2020. All the sampling points in Bugarura each showed an elevation in carbon dioxide concentration from the September 2020. Bugarura1,2,3 and 4 whose average before September 2020 was 1.6%, 0.9%, 1% and 2.5% respectively saw their average concentration rise from September onwards to 4%, 2.2%, 3.6% and 6.8% respectively. The peak of 10.7% carbon dioxide was observed in October 2020.

References

1. Bogue, R. R., Schwandner, F. M., Fisher, J. B., Pavlick, R., Magney, T. S., Famiglietti, C. A., Cawse-Nicholson, K., Yadav, V., Linick, J. P., North, G. B., and Duarte, E.: Plant responses to volcanically elevated CO2 in two Costa Rican forests, Biogeosciences, 16, 1343–1360, https://doi.org/10.5194/bg-16-1343-2019, 2019.
2. BUREAU DE LA CHEFFERIE DE BUKUMU. (2016), Tableau synoptique général de la population Congolaise, du Territoire de Nyiragongo.
3. Burton, M. R., Sawyer, G. M., and Granieri, D.: Deep Carbon Emissions from Volcanoes, Rev. Mineral. Geochem., 75, 323–354, https://doi.org/10.2138/rmg.2013.75.11, 2013.
4. Chiodini, G., Cioni, R., Guidi, M., Raco, B., and Marini, L.: Soil CO2 flux measurements in volcanic and geothermal areas, Appl. Geochem., 13, 543–552, https://doi.org/10.1016/S0883- 2927(97)00076-0, 1998.
5. Dietrich, V. J., Fiebig, J., Chiodini, G., and Schwandner, F. M.: Fluid Geochemistry of the Hydrothermal System, in: Nisyros Volcano, edited by: Dietrich, V. J., Lagios, E., and Bachmann, O., Springer, Berlin, p. 339, 2016.
6. Eichelberger, J. C. (1980), Vesiculation of mafic magma during replenishment of silicic magma reservoirs, Nature, 288, 446–450, doi:10.1038/288446a0.
7. Farrar, C.D., M.L. Sorey, W.C. Evans, J.F. Howle, B.D. Kerr, B.M. Kennedy, Y. King, and J.R. Southon (1995), Forest-killing diffuse CO2 emission at Mammoth Mountain as a sign of magmatic unrest, Nature, 376, 675–678.
8. Faustin Safari Habari, Marcel Bahati Rusimbuka, Arsène Tumaini Sadiki, Mathieu Mapendano Yalire, Charles Muhigirwa Balagizi. Monitoring of CO2 in the Nyiragongo Volcano Cracks on Bugarura and Munigi Sites from January 2019 to January 2020. International Journal of Natural Resource Ecology and Management. Vol. 6, No. 2, 2021, pp. 38-41. doi: 10.11648/j.ijnrem.20210602.12
9. Guillaume Boudoire, A. Rizzo, A. Di Muro, F. Grassa, M. Liuzzo. Extensive CO2 degassing in the upper mantle beneath oceanic basaltic volcanoes: First insights from Piton de la Fournaise vol- cano (La Réunion Island). Geochimica et Cosmochimica Acta, Elsevier, 2018, 235, pp.376 - 401. 10.1016/j.gca.2018.06.004. hal-01858782
10. Houlié, N., Komorowski, J. C., de Michele, M., Kasereka, M., and Ciraba, H.: Early detection of eruptive dykes revealed by normalized difference vegetation index (NDVI) on Mt. Etna and Mt. Nyiragongo, Earth Planet. Sc. Lett., 246, 231–240, https://doi.org/10.1016/j.epsl.2006.03.039, 2006.
11. Koepenick, K., S. Brantley, J. Thompson, G. Rowe, A. Nyblade, and C. Moshy (1996), Volatile emissions from the crater and flank of Oldoinyo Lengai volcano, Tanzania, J. Geophys. Res., 10, 13,819-13,830.
12. Lary, Louis & Loschetter, Annick & Gal, Frederick & Vanoudheusden, Émilie & P., Rocher & Burnol, André & Collignan, Bernard. (2016). Risques liés aux émissions naturelles de CO2 dans l'agglomération de Clermont-Ferrand.
13. Lewicki, J.L., C. Connor, K. St-Amand, J. Stix, and W. Spinner (2003), Self-potential, soil CO2 flux, and temperature on Masaya volcano,

Nicaragua, Geophys. Res. Lett., 30, 1817.

14. Mason, E., Edmonds, M., and Turchyn, A. V.: Remobilization of crustal carbon may dominate volcanic arc emissions, Science, 357, 290–294, 2017.
15. Murphy, M.D., Sparks, R.S.J., Barclay, J., Carroll, M.R., Lejeune, A.-M., Brewer, T.S., Macdonald, R., Black, S., Young, S., 1998. The role of magma mixing in triggering the current eruption at the Soufriere Hills volcano, Montserrat, West Indies. Geophysical Research Letters 25, 3433–3436.
16. Pérez, N. M., Hernández, P. A., Padilla, G., Nolasco, D., Barrancos, J., Melían, G., Padrón, E., Dionis, S., Calvo, D., Rodríguez, F., Notsu, K., Mori, T., Kusakabe, M., Arpa, M. C., Reniva, P., and Ibarra, M.: Global CO2 emission from volcanic lakes, Geology, 39, 235–238, https://doi.org/10.1130/G31586.1, 2011.
17. RizzoA.,GrassaF.,InguaggiatoS.,LiottaM.,LongoM.,MadoniaP.,BruscaL.,CapassoG.,MoriciS.,RouwetD.andVitaF.(2009)Geochemicalevaluationofobservedchangesinvolcanicactivityduringthe2007eruptionatStromboli(Italy).J.Volcanol.Geoth.Res.182,246–254.
18. Salazar, J.M., P.A. Hernández, N.M. Pérez, G. Melían, J. Alvarez, F. Segura, and K. Notsu (2001), Diffuse emission of carbon dioxide from Cerro Negro volcano, Nicaragua, Central America, Geophy.s Res. Lett., 28, 4275–4278.
19. Shaw A.M., Hilton D. R., Macpherson C.G. and Sinton J.M.(2004)TheCO2 –He–Ar–H2OsystematicsoftheManusback-arcbasin:resolvingsourcecompositionfromdegassingandcontaminationeffects.Geochim.Cosmochim.Acta68,1837–1855.
20. Sorey, M. L., Evans, W. C., Kennedy, B. M., Farrar, C. D., Hainsworth, L. J., and Hausback, B.: Carbon dioxide and helium emissions from a reservoir of magmatic gas beneath Mammoth Mountain, California, J. Geophys. Res.-Sol. Ea., 103, 15303–15323, https://doi.org/10.1029/98JB01389, 1998.
21. Sparks, R. S. J., H. Sigurdsson, and L. Wilson (1977), Magma mixing: A mechanism for triggering acid explosive eruptions, Nature, 267, 315–318, doi:10.1038/267315a0.
22. Symonds, R. B., Gerlach, T. M., and Reed, M. H.: Magmatic gas scrubbing: implications for volcano monitoring, J. Volcanol. Geotherm. Res., 108, 303–341, https://doi.org/10.1016/S0377- 0273(00)00292-4, 2001.
23. Werner, C., Fischer, T., Aiuppa, A., Edmonds, M., Cardellini, C., Carn, S., . . . Allard, P. (2019). Carbon Dioxide Emissions from Subaerial Volcanic Regions: Two Decades in Review. In B. Orcutt, I. Daniel, & R. Dasgupta (Eds.), Deep Carbon: Past to Present (pp. 188-236). Cambridge: Cambridge University Press.
24. Williams-Jones, G., Stix, J., Heiligmann, M., Charland, A., Lollar, B. S., Arner, N., Garzón, G. V., Barquero, J., and Fernandez, E.: A model of diffuse degassing at three subduction-related volcanoes, Bull. Volcanol., 62, 130–142, 2000.