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Temperature Evolution in Active Fractures at the Summit Site of Nyiragongo Volcano From 2003 to 2019, Virunga Volcanic Zone, East African Rift, Drc

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ABSTRACT

Temperatures in the fractures measured in the site at the top of Nyiragongo volcano in Virunga volcanic zone in DRC at its southern flank have since 2003 after this volcano eruption on January 17, 2002 to 2019, November; have experienced variations due not only to its magmatic activity but also to cosmic movements. Indeed, the earth and the moon describe each one an orbit around the sun; the three stars attract each other according to the universal law of gravitation or law of universal attraction discovered by Isaac Newton. During the perihelion, the distance between the earth and the sun is short therefore the sun attraction on the earth is great compared to the other the year periods. This attraction is exerted mainly on fluids including the lava lake of Nyiragongo volcano. The lava lake level of rises in the well of the Nyiragongo crater and even overflows. The temperature in the fracture near the crater is also increasing and this explains the peaks at this site during period. During the new and full moon, the moon also exerts a great attraction in this lava lake of this volcano and also accentuates the increase of temperature at this site.

Key words: Temperature, Nyiragongo, Fracture, East African Rift

1. Introduction

The continental heat flow is very complex in nature. It is a transmission of heat (or thermal energy) through a body and is expressed in W/m^2. In fact, it is a sum of three components: the mantle flow, the contribution of radioactive elements in the crust and the transient effect due to recent tectonic-magmatic events (G. H. Darwin). The heat released in the active fractures of Nyiragongo Volcano is a result of the last element. The terrestrial heat flux is not measured directly, but is obtained from the geothermal gradient and conductivity (O. Bourgeois, D. Tainoff, N. Mingo, B. Vermeersch and J.-L. Barrat, 2008,).

In volcanoes and volcanic regions, there is a significant upwelling of heat flows to the surface in the form of both sensible and latent heat. Convection is a mode of heat transfer where heat is advected by at least one fluid. However, a simple linear relationship between heat flow and heat production is not valid for tectonically active regions such as Virunga because of the transient effect due to magmatic intrusions and increased mantle heat flow (Yuan Dong, 2016).

Heat is then transferred much more efficiently than by thermal conduction or radiation, which are the two other modes of heat transfer. This very common physical phenomenon occurs in many systems (earth's mantle, star,...) in various forms (P. Melchior and B. Ducarme, 1989).

The eruption of the Nyiragongo volcano on 17 January 2002 reactivated the fractures traced by the 1977 eruption and earlier eruptions and extended some of them southwards into the city of Goma. These north-south oriented fractures cut through populated areas and thus pose a permanent threat to the cities of Goma and Gisenyi and their surroundings. Prior to the eruption of this volcano in 2001, an increase in temperature was observed in the Shaheru fracture and in the Rusayo area. Therefore, geothermal monitoring of these active fractures at the surface may give an early warning of a future eruption. This is because the internal geothermal heat recorded in fractures in a volcanic area such as Virunga is produced by the ascent to the surface of magma by conduction, which consequently dissipates by underground convection of volcanic heat to the surface (Michael M. Modest, 2003; Müller and Tommaso Ruggeri, 1998). The monitoring of temperature flow in fractures is a measurement technique practiced at the OVG since 2003;

the measurement is carried out by contact with a probe (thermistor) because the generations of the Virunga volcanoes like those of the Canary Islands are interpreted as being the manifestation on the surface of deep ascending mantle plumes or hot spots (W. J. MORGAN 1971).

2. METHODOLOGY

In the elaboration of the present work, we used all the temperature data collected in the Summit sites available at the OVG since 2003, after calculating the daily average, arranged them in chronological order after small corrections, validated them and drew a curve with the Excel software. We also read the literature for interpretation and discussion of the results obtained.

2. A. Measuring Instruments and Data

2. *A.1 Measuring instruments*

From February 2002 to March 2003, we used a Japanese thermocouple to measure the temperature in the fractures. The measurements were punctual, and we could not reach all the chosen sites at the same time.

In March 2003, OCHA funded a project that was executed by IPGP for the acquisition of **TinyTag Plus 2** thermal sensors manufactured by GEMMINI consisting of a probe and a data logger.

A.2. Measuring instrument
Thermal sensor TINYTAG Plus 2

(**Recording thermometer**) PT 1OO Download cable

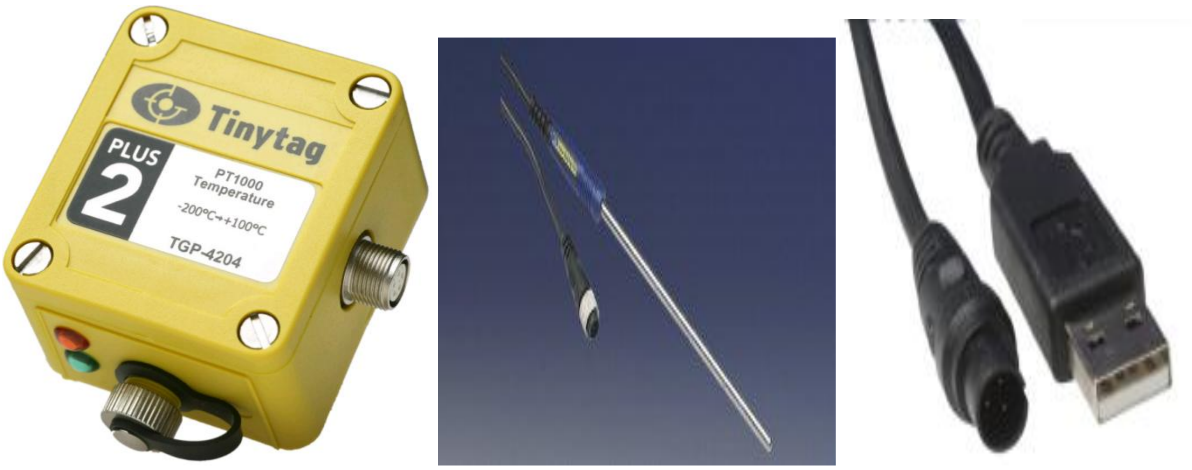


Fig.1. A. The Tintag Pt100 sensor B. The PT 100 probe C. The USB download cable

High Temperature PT100 Probe with 1.5 m cable is a high temperature probe with a 1.5 m cable that monitors temperatures from -50°C to +600 °C. The PT100 probe measures the change in resistivity of a platinum filament wrapped around a glass rod. Typically, PT100 probes have a resistivity value of 100 ohms at 0°C. The resistivity variation is approximately 0.4 ohms/°, with an accuracy of +/- 0.3. Data logger using PT100 probe -50 to +300/600 °C the TGP-4104 uses PT100 to measure very high temperatures.

2.B. The data used

The data used were recorded by the Tinytag TGP-4104 sensors and downloaded by the Tinytag Explorer software. A correction of the data is made before their validation from the data of the calibration of the probes made every two years by the thermostat bath that for a regular calibration in all the sites of measurement.

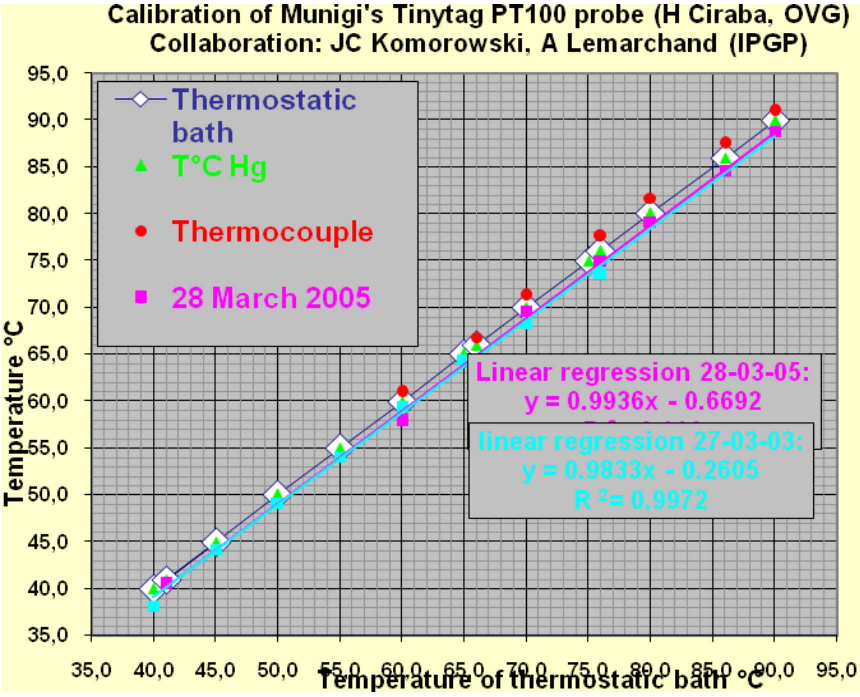
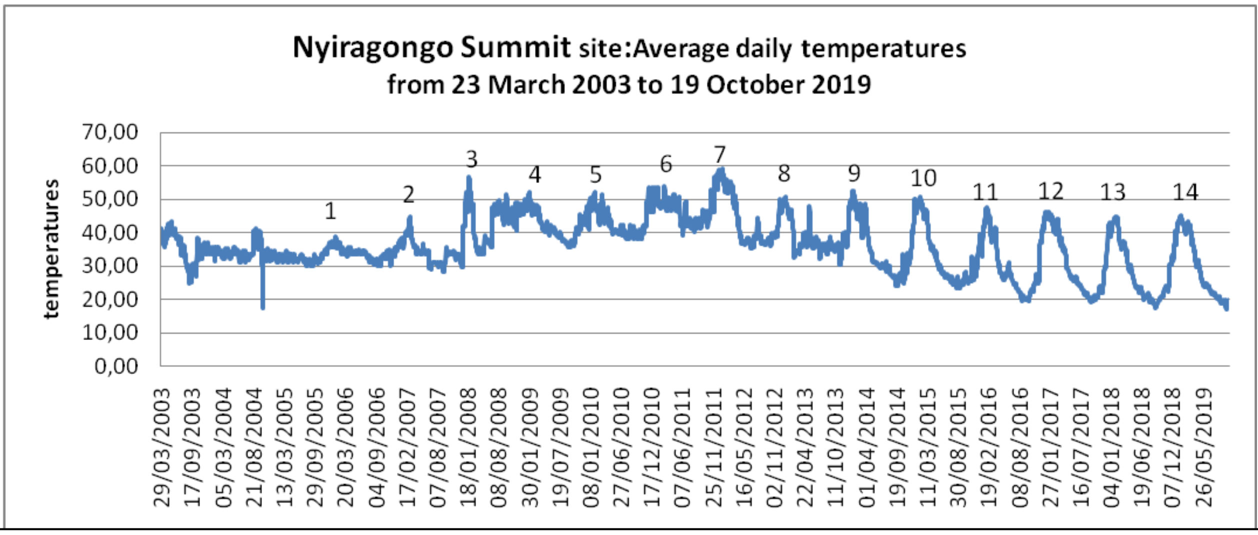


Fig 2 Probe calibration curve

3. PRESENTATION AND DISCUSSION OF THE RESULTS

3.1. Presentation of the results

From 29 March 2003 to 19 October 2019, temperatures at Nyiragongo Summit experienced a rollercoaster pattern marked by an increase from 2013 to January 2012 and a downward trend from January 2013 to October 2019. The rise in average daily temperatures with peaks almost at the same time each year observed at this site are between mid-December and mid-March, i.e. around 21 December to 21 March each time. This phenomenon is observed from January 26, 2006 to 2019.



1=27/01/2006 **2**=07/03/2017 **3**=26/01/2008 **4**=29/01/2009 **5**=25/01/2010 **6**=23/01/2011
7=30/01/2012 **8**=05/12/2013 **9**=10/01/2014 **10**=03/01/2015 **11**=06/02/2016 12=04/02/2017
13 =16/01/2018 14= 13/01/2019

Fig.3. Nyiragongo Summit site: Average daily temperatures from 23 March 200 to 19 October 2019

3.2. Discussion of the results

Nyiragongo is one of two African volcanoes with a permanent lava lake in its crater. The temperature measurement site at Nyiragongo Summit is located 10m from the crater of this volcano and therefore not far from the vent and lava lake. Thus, the upward and downward movement of the lava lake in the crater shaft causes heat to spread in a short time by thermal conduction to this site located on the fracture that runs from the crater to the southern flank of the volcano.

The cyclic or periodic fluctuations, especially the temperature peaks, occur between mid-December and mid-March, i.e. from about 21 December to 21 March. The earth in its movement around the sun on the orbit during this period is in the **perihelion** phase**.** The Earth-Sun distance, which is 149 million km, on average, varies during the year. The Earth passes each semester, alternately, at the **perihelion**, i.e. it is at this moment closest to the sun and at the **aphelion**, i.e. it is at this moment farthest from the sun. The distance between these two distances is set by the **eccentricity** (http://www.astronoo.com/fr/articles/excentricite-de-la-terre.htmlUpdated 01 June 2013)**.** The stars close to the Earth and more particularly the Moon and the Sun exert gravitational forces on it. This result in a tidal generating force that tends to deform the Earth into an ellipsoid whose principal axis is oriented towards the disturbing star (Julien Boerez, 2013 p). Indeed, the planets of the solar system move around the Sun by describing a curve of the shape of a slightly flattened circle that we call an ellipse. This curve has 2 particular points which we call "focus", the Sun occupying one of these points. This particularity was noticed by Kepler while studying the orbit of the planet Mars (www.les-pleiades.asso.fr). During perihelion, the distance between the earth and the sun is short (see fig.4 A and B), therefore the attraction of the sun on the earth is great compared to the other periods of the year. This attraction exerts a lot on fluids (Odile Guérin, 2004; P. Melchior and B. Ducarme, 1989,) including the lava lake of the volcano for our case. The level of the lava lake rises in the crater shaft of Nyiragongo and even overflows when the attraction is great. It should be noted that this phenomenon can also be due to a great magmatic activity in the deep primary reservoir.

This explains the temperature peaks at this site during this period (https://fr.wikipedia.org/wiki/Périhelie). The table below shows the dates of the aphelion and perihelion for the latter, which is between 02 and 05 January each year; this corresponds to the maximum of the peaks numbered in figure 3. As the lava is viscous, the rise is slow, as well as by conduction of heat to the thermal sensor. There is therefore a time lag between the perihelion date and the peak.

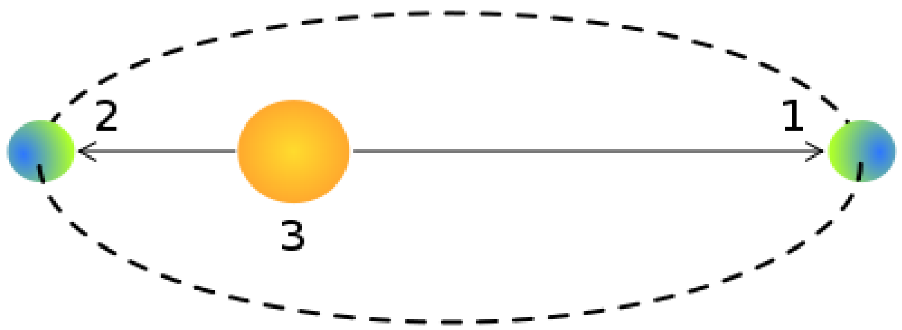


Fig.4 A Earth orbit 3= Sun and 2= Earth at Perihelion 1. The Earth at Aphelion

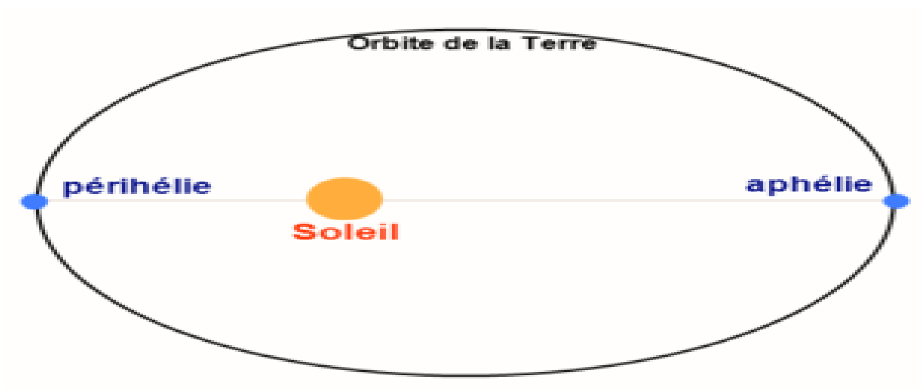


Fig. 4 B Earth's orbit the sun and the earth at perihelion and aphelion The planet is at perihelion at point n °2. The simplified diagram of the orbit of the Earth around the Sun :sourcehttps://fr.wikipedia.org/wiki/Périhelie accessed on 28/ 11/ 2019)

Table N°1. The dates of aphelion and perihelion-source Perihelion:

source https://www.imcce.fr/fr/grandpublic/temps/saisons/presentation_saisons.html

Accessed on 13/12/2019

Year	Perihelion		Aphélie	
	Date	Time	Date	Time
2007	3 January	20:00	7 July	00:00
2008	3 January	00:00	4 July	08:00
2009	January 4	15:00	4 July	02:00
2010	3 January	00:00	July 6	11:00
2011	3 January	19:00	4 July	15:00
2012	5 January	00:00	5 July	03:00
2013	2 January	05:00	5 July	15:00
2014	January 4	12:00	4 July	00:00
2015	January 4	07:00	July 6	19:00
2016	2 January	23:00	4 July	16:00
2017	January 4	14:00	3 July	20:00
2018	3 January	06:00	July 6	17:00
2019	3 January	05:00	4 July	22:00
2020	5 January	08:00	4 July	12:00

The cyclic rise of the lava lake and temperature and the time lag of this rise are also accentuated by the attraction of the moon on the lava lake. Indeed, the full and newmoon have certain effects on the earth's tides and on fluids in general. They could thus act on the activity of volcanoes, particularly in our case on the upward and downward movement of the lava lake level. This was suggested by Italian researchers Gianluca Sottili and Danilo Palladino in their studies of the Stromboli crater between June 2010 and October 2011 published in Terra Nova on 21 February **2012** (Gianluca,Sottili and Danilo M. Palladino, 2012) **.**

Indeed, the attraction of the Moon is stronger during these two lunar periods, the Sun comes either to decrease or increase this attraction according to this or that period. At the new moon or at the full moon, the Sun, the Moon and the Earth are aligned, so the forces of attraction are added, which generates higher tides (spring tides). During the first and last quarters, the forces of attraction of the Moon and the Sun are opposed, and the tides are weaker (neap tides). These phenomena also occur on the lava lake of Nyiragongo volcano. Overflows of lava in the crater shaft of the volcano generally occur during these two phases of the moon during perihelion. Knowing that the masses of the Earth ($5.9736.10^{24}$kg), the Sun ($1.9891.10^{30}$kg) and the Moon ($7.3477.10^{22}$kg) as well as the distances Sun-Earth (149,600,000,000 m) and Earth-Moon (384,400,000 m) the gravitational force exerted by the Sun on the Earth (and vice versa) ($3.54.10^{24}$N) is almost 180 times greater than that exerted by the Moon on the Earth ($1.98.10^{22}$N). The influence of the Moon on the Earth (and perhaps in connection with volcanism) is related to the attraction it exerts on the land masses (Odile Guérin, 2004). According to G. H. Darwin, 1989 and www.lecalendrier-lunaire.fr, the major conclusion of the attraction of the Moon on the terrestrial fluids is due to the fact of its proximity to the Earth; the tidal acceleration caused by the Moon is 2.2 times that caused by the Sun. The second is that this tidal acceleration is not confined to the seas and oceans alone, but to the entire Earth. The difference in amplitude between ocean tides (up to 16 meters) and land tides, including the volcano's lava lake, comes from the characteristics of the environment and its ability to deform.

Thus, the temperature peaks observed for more than a decade at the Nyiragongo Summit site are in January during perihelion and between December and January of each year (G. H. Darwin, 1989 and www.lecalendrier-lunaire.fr Odile Guérin, *Tout savoir sur les marées*, Éditions Ouest-France, 2004)

CONCLUSION

The temperature at the Nyiragongo volcano summit site has been fluctuating since 2006, with the highest temperatures occurring at almost the same time.The temperature curve has from 2005 to 2010 an increasing trend and from 2010 to 2018 the trend is decreasing with peaks that are cyclic consecutive to the perihelion period during which the earth is close to the sun. Thus, the activity of the lava lake is not only due to the activity in the magma chamber deep inside the volcano but also to the attraction of the moon and the sun on the lava in the crater of the volcano. Thus, continuous measurement of temperature (heat flow) in fractures is one of the elements of volcano monitoring.

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