Chapter 11

Nyiragongo (Democratic Republic of Congo), January 2002: a major eruption in the midst of a complex humanitarian emergency

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11.1 Lava flows in town: the 17 January 2002 Nyiragongo eruption

Nyiragongo is a 3470 m high volcano located in the western branch of the East African Rift in the Democratic Republic of Congo (DRC), close to the border with Rwanda. It has a 1.3 km wide summit crater that has been filled with an active lava lake since 1894. The area is affected by frequent damaging tectonic earthquakes and by permanent passive degassing of carbon dioxide (CO_2). Fatal concentrations of CO_2 can accumulate in low-lying areas, threatening the permanent population and internally displaced persons (IDPs) in refugee evacuation centres.

On 17 January 2002 fractures opened on Nyiragongo's upper southern flanks triggering a catastrophic drainage of the lava lake (Figure 11.1). An estimated 25 million cubic metres of lava erupted from many vents along the fractures, which rapidly propagated South towards and into the city of Goma located 17 km away on the shores of Lake Kivu. A small volume of lava entered the lake, which contains deep CO_2 and CH_4 (methane) gas-charged waters. This raised concerns of a potential overturn of the lake, generating lethal gas flows, but the lake was not disturbed. Nyiragongo volcano is responsible for 92% of global lava-flow related fatalities (ca. 824) since 1900. The eruption was accompanied by an unprecedented level of felt earthquakes (Allard et al., 2002, Komorowski et al., 2002/2003, Tedesco et al., 2007b).

Two main lava flows entered the city producing major devastation, and forcing the rapid exodus of most of Goma's 300,000 to 400,000 inhabitants across the border into neighbouring Rwanda. There were international concerns about the evacuation causing an additional humanitarian catastrophe exacerbating the ongoing regional ethnic and military conflict. Lava flows destroyed about 13 % of Goma, 21% of the electricity network, 80% of its economic assets, 1/3 of the international airport runway and the housing of 120,000 people. The eruption caused about 470 injuries and about 140 to 160 deaths mostly from CO_2 asphyxiation and from the explosion of a petrol station near the active hot lava flow (Komorowski et al., 2002/2003, Baxter et al., 2003).

This was the first time in history that a city of such a size had been so severely impacted by lava flows. The eruption of Nyiragongo in 1977 produced extremely fluid, fast-moving (up to 60 km/h) lava flows (Figure 11.1) that entirely covered several villages at night thus killing an estimated 600 persons, but the lava did not reach Goma.

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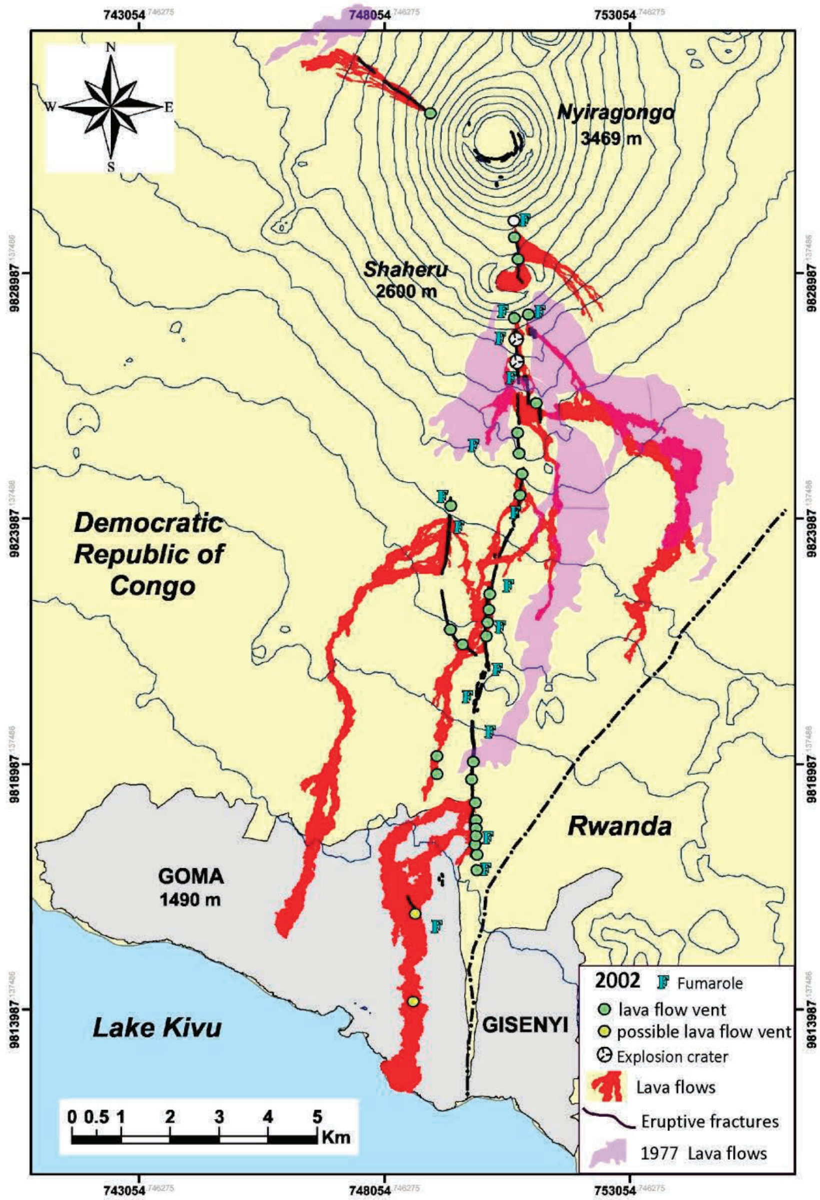

Figure 11.1 Map of the eruptive fractures, lava vents, and lava flows emplaced during the 17 January 2002 and 1977 eruptions of Nyiragongo volcano, Democratic Republic of Congo (modified from Komorowski et al. (2002/2003)).

11.2 Multiple geohazards and a complex humanitarian emergency

With its rapidly expanding demographics and a large numbers of internally displaced persons (IDPs), the city of Goma (ca. 1 million people in 2014) is one of the highest volcanic risk areas in the world. Indeed, this area is not only threatened by future lava flows from lava-lake draining eruptions of Nyiragongo, but also lava flows from Nyamuragira volcano. Long lava flows from this neighbouring volcano, which erupts on average every two years, threaten the northern

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shores of Lake Kivu and the town of Sake, where large numbers of IDPs shelter (Favalli et al., 2006, 2009, Chirico et al., 2009, Smets et al., 2014). Ash falls, sulfuric acid, chlorine, and fluorine-rich gases affect public health (Sawyer et al., 2008), the water supply and crops. Other hazards include major earthquakes and potentially catastrophic outbursts of CO_2 and methane gas from Lake Kivu (Schmid et al., 2005, Tassi et al., 2009) and landslides (Figure 11.3). These acute geohazards can develop in a cascading sequence and are superimposed on a decade of devastating insecurity and military conflicts in the densely populated Kivu region, that have caused a complex emergency requiring a major humanitarian effort and the largest ongoing UN peace-keeping mission (Komorowski et al., 2002/2003).

*Figure 11.2 **Top** and **middle**: Lava flows invading the city of Goma on 17 January 2002 (photo K. Mahinda, GVO, 2002); **Bottom**: Fractures propagating through the village of Monigi 14 km away from Nyiragongo near the city of Goma as magma migrated from the central conduit South towards lake Kivu (see Figure 11.4) (photo J-C Komorowski, January 23 2002).*

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The eruption caused a major humanitarian emergency that further weakened the already fragile lifelines of the population in an area subjected to many years of regional instability and military conflicts. The medical and humanitarian community feared a renewal of cholera epidemics that caused a high mortality in refugee evacuations centres after the 1994 genocide. However, rapid and efficient response by relief workers from UN agencies, numerous non-governmental organisations (NGOs), and local utility agencies prevented major epidemics. Epidemiological surveillance found no major increases in infectious diseases (Baxter & Ancia, 2002, Baxter et al., 2003).

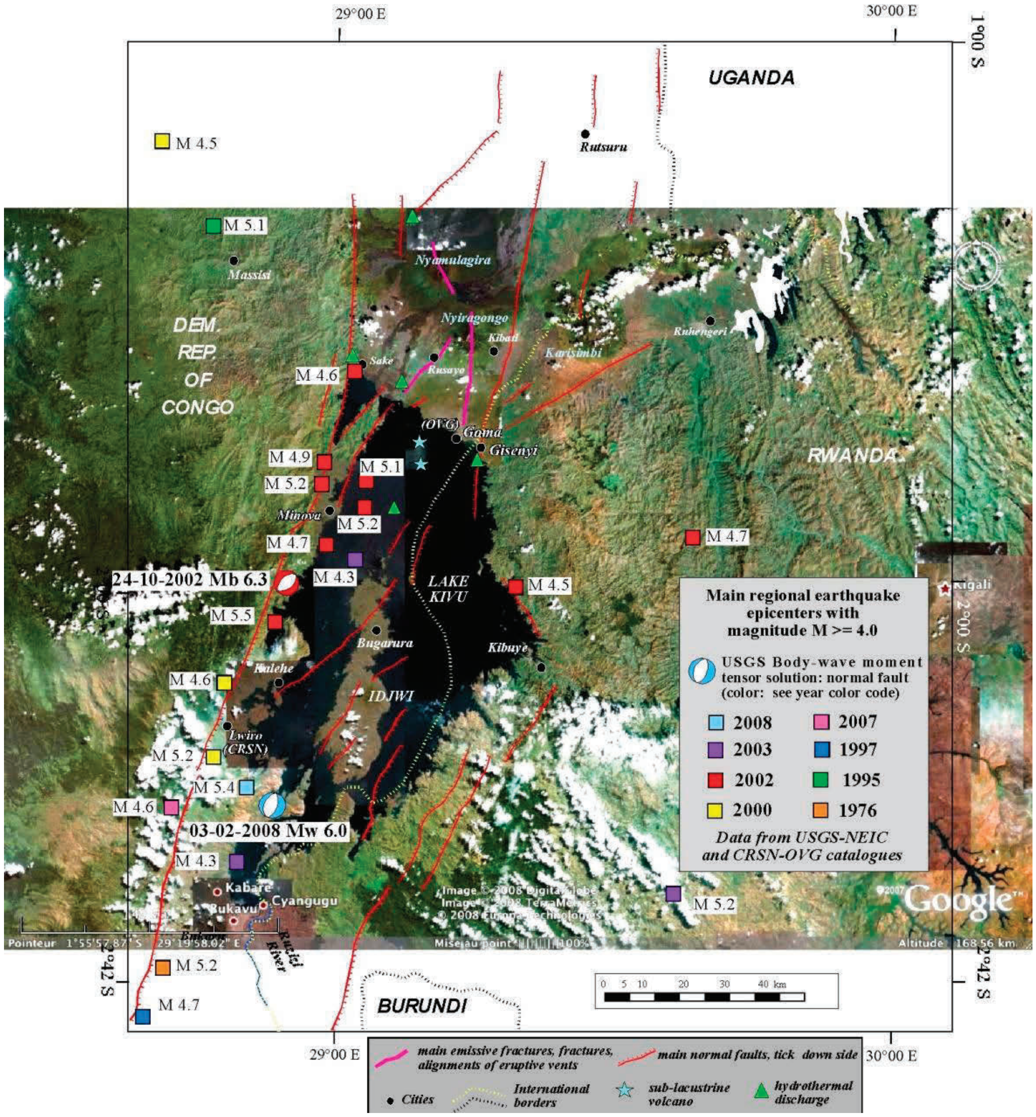

Figure 11.3 Volcanic and seismo-tectonic general setting of the lake Kivu and Virunga Volcanic Zone (Democratic Republic of Congo, Rwanda, Burundi, Uganda) in the western branch of the East African Rift System. Main normal rift faults and lake Kivu data taken from Pouclet (1977), Villeneuve, (1980), Bellon & Pouclet (1980), Ebinger (1989a, 1989b) and Kasahara et al. (1992, Degens et al.,(1973), Wong & Von Herzen (1974). Main earthquake epicenters with magnitude ≥ 4 since 1973 taken from the USGS National Earthquake Information Center (NEIC) and data from the CRSN and the OVG (Goma, RDC), satellite image background from Google Earth (modified from Komorowski et al., 2004 and references therein).

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11.3 Lessons learned

Despite being in the midst of a civil war, a lack of funding, institutional support and adequate monitoring equipment, the Goma Volcano Observatory (GVO) scientists successfully made some exceptionally valuable observations about increasing fumarolic and seismic activity. Data from two distant seismic stations were interpreted, as other equipment had been vandalised during the years of military conflict. Those signs were correctly interpreted by GVO as potentially indicating that an eruption could occur, although the precise scenario of a far-reaching flank fissure eruption could not be forecast without an adequate monitoring network. Nevertheless, the GVO played a key role in the recognition of the unrest 1 year prior to the eruption and in providing expert advice to the UN authorities once the eruption began. Memory of the 1977 devastating lava flows triggered life-saving actions by villagers, including panic-less self-evacuation. This, in combination with the presence of a large humanitarian community in Goma and the advice provided by the GVO undoubtedly contributed to the low number of fatalities given the scale of the eruption (Komorowski et al., 2002/2003, Ruch & Tedesco, 2003).

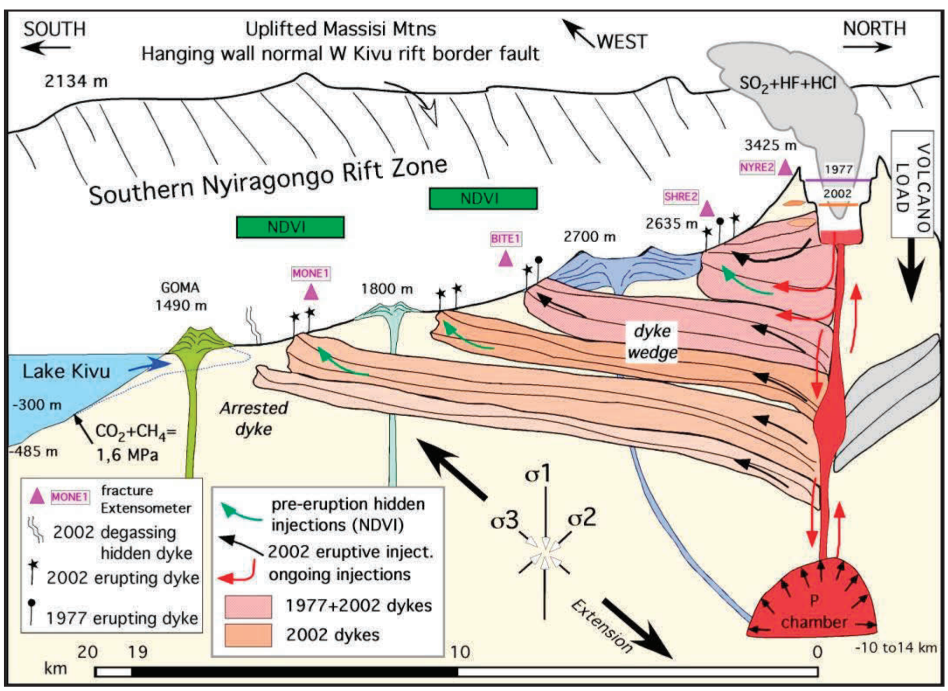

Figure 11.4 Conceptual model of the southern Nyiragongo rift zone and its volcanic activity in the context of the North Kivu tectonic rift area and gas-charged Lake Kivu. (Based on information from (Komorowski et al., 2006, Houlie et al., 2006).

For Nyiragongo, the IDNDR Decade programme had not achieved its goals as clearly stated in the 1994 Goma Declaration (Casadevall & Lockwood, 1995). The response to the 2002 Nyiragongo eruption was remarkable, with significant support provided rapidly by the international humanitarian and scientific community under the coordination and with funding from UN agencies. This support came from international and regional NGOs, government agencies, donor countries and academic research programmes (Tedesco et al., 2007a). Had the DRR goals for Nyiragongo, laid out as part of the International Decade for Natural Disaster Reduction (IDNDR) and stated in the 1994 Goma Declaration (Casadevall & Lockwood, 1995) been achieved prior to this eruption, such a complex response may have been unnecessary.

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Therefore one of the first tasks of the post-crisis response to the 2002 eruption was to establish a modern operational volcano monitoring network and team. Thus, the GVO was significantly strengthened and a new multi-parameter modern monitoring system was installed gradually along with capacity-building programmes. All these efforts have significantly improved the technical and analytical capabilities of the GVO in monitoring the activity of the Virunga volcanoes (including Nyiragongo and Nyamuragira).

11.4 The way forward: the Goma Volcano Observatory

Since 2002, a new large lava lake has formed within the 1000 m deep crater and is associated with a significant sulfur, chlorine, and fluorine-rich gas plume, one of the largest in the world. The level of lava has risen slowly but continuously by at least 500 m since October 2002, resting about 400 m below the rim, and only 130 m below the level at the time of the 2002 drainage. There is considerable scientific uncertainty regarding future scenarios (Komorowski et al., 2002/2003):

1. What is the threshold level of the lava lake required to trigger another release of lava through its flanks towards the south like in 1977 and 2002?

2. How likely is it that magma will be channelled away from the summit crater through the highly fractured southern flanks of Nyiragongo?

3. In a future lateral eruption, will magma propagate faster and further towards the water-saturated ground near lake Kivu, thus increasing the likelihood of explosive eruptions within the city of Goma?

4. In the worst-case scenario, could magma propagate below the deep gas-charged basin of lake Kivu to trigger subaqueous volcanic eruptions and potential catastrophic lake-overturn events releasing large volumes of CO_2 and methane into the environment?

Successful volcanic risk mitigation depends on a series of integrated timely actions. These include: a permanent secured multi-parameter real-time monitoring network; quantitative hazard and risk assessment that quantifies uncertainty and fills knowledge gaps; early-warning systems; emergency and long-term planning; and awareness programmes for crisis managers, decision-makers and the public. Given the high volcanic risk in the Goma area, all these efforts must be further strengthened to support decision-making by the authorities.

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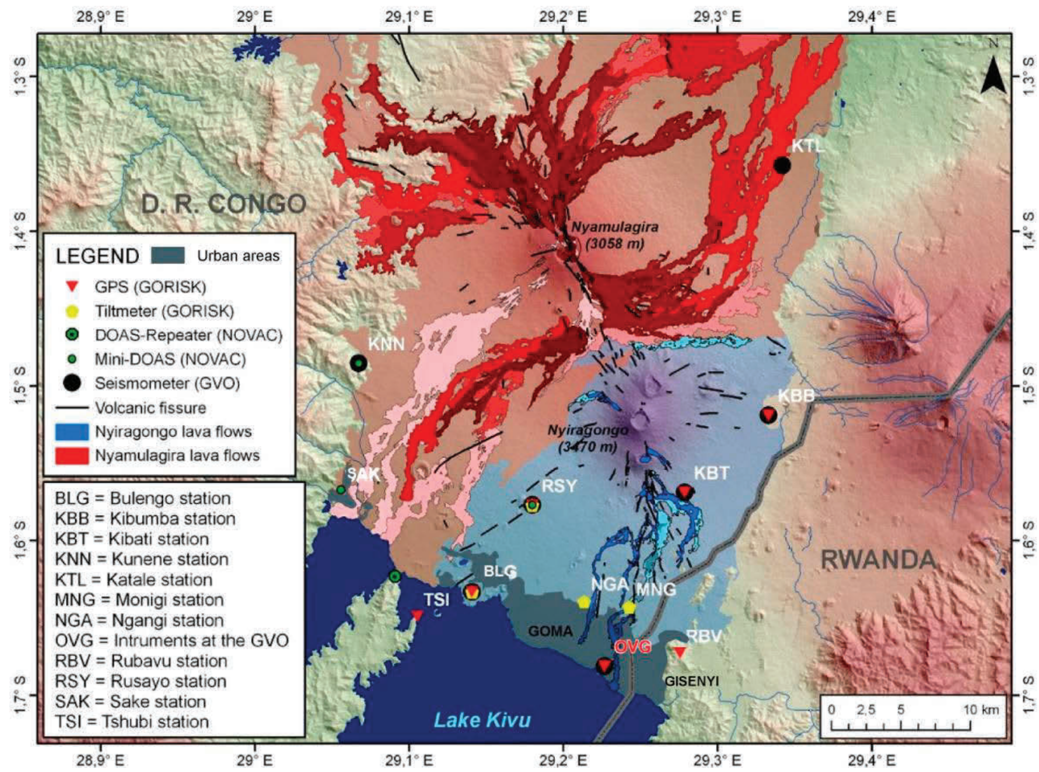

Figure 11.5 The current multi-parameter monitoring system of the Goma Volcanological Observatory (see legend for the techniques). In cooperation with foreign institutions or universities, GVO is involved in: geochemistry surveys, investigation of Mazuku (pockets of CO_2) CO_2 ground degassing, Lake Kivu chemical and physical surveys, satellite imagery and DEM mapping, geological and structural mapping, lake Kivu stability modelling, lava flow paths modelling, hazard and risk maps, ground deformation benchmarks, continuous temperature measurements and monitoring of the width of eruptive fractures. Some stations are no longer working due to equipment vandalism (GVO; WOVO). Image modified from Smets et al. (2014).

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