Physical volcanological study of the Rungwe volcanic province, Tanzania

Karen Fontijn
Supervisor: Patric Jacobs

Department of Geology and Soil Science, Ghent University

Public defence: 18 January 2011

The understanding of volcanoes and volcanic processes has made important steps forward in the second half of the 20th century. The first advances in the scientific study of volcanology were made through two approaches: 1) careful descriptions of eruptive processes over the centuries, 2) the systematic documentation of volcanic deposits and products, which enabled to extract essential information on processes occurring at depth and during past eruptions. In the last few decades, major advances were achieved using new approaches such as theoretical, numerical and analogue modelling of volcanic processes, remote sensing and ground-based monitoring techniques, but also in human-oriented approaches, aiming at understanding the impact of volcanic eruptions. This thesis illustrates how the field-based approach, i.e. collecting a large amount of quantitative field data, is essential in retrieving crucial information on a volcano's past eruptive history to anticipate and understand its potential future behaviour, and in obtaining insights into so far poorly understood processes.

Many hazardous volcanoes, especially those in low- and middle-income countries, have not been studied and are not regularly monitored, which raises significant concerns within the scope of hazard assessment and risk mitigation. A first step towards detailed hazard and risk assessment has been made for the Rungwe Volcanic Province (RVP) in Tanzania, a densely populated region comprising three major volcanoes: Ngozi, Rungwe and Kyejo. The thesis presents a physical volcanological study of the RVP. The research mostly focuses on Rungwe volcano, the largest central volcano in the RVP. Preliminary work that was done in the past provided clues that interesting findings could be made about recent eruptions in the region, and of Rungwe in particular. A detailed study of these deposits was needed to characterize the eruption style, intensity and recurrence rate of the RVP volcano.

In a first stage of the research, the volcano-tectonic architecture of the RVP, i.e. the relationship between volcanic and tectonic activity, is investigated. Observations extracted from geo-referenced air photos and from a Digital Elevation Model document the spatial distribution and relation between volcanic centres and tectonic lineaments. The observed tectonic lineaments are consistent with current tectonic models for the RVP. A strong control of tectonic activity over the location of the three main central volcanoes that are considered active, i.e. Ngozi, Rungwe and Kyejo, is evidenced. Ngozi and Rungwe volcanoes are both located at the intersection of active faults characterizing the rift systems surrounding the RVP. Especially Rungwe shows evidence of flank instability related events, possibly as a result of tectonic activity. From remote sensing analysis and complementary field work, it was indeed shown that Rungwe has been affected by at least one partial sector collapse generating a debris avalanche travelling at least 22 km to the SW.

The central theme of the thesis is to document the recent eruptive history of the RVP, and Rungwe in particular, which will serve as a basis for future hazard assessment. As a first step towards unravelling the eruptive history, systematic geological mapping and stratigraphic logging are necessary inputs to gain insights in the general style of eruptive processes characterizing the volcano. The Holocene record of explosive eruptions from Rungwe volcano, and also partly from Ngozi volcano, is presented. Field data and geochemical data allowed identification of six pumice fallout deposits and one pyroclastic flow deposit which each could be assigned to either Ngozi or Rungwe, based on spatial distribution and/or characteristic chemical signatures. Radiocarbon dating on palaeosols constrains the maximum age of each eruption.

Rungwe had at least five pumice fallout eruptions at a range of scales, the oldest and most significant one being a Plinian eruption at ca. 4 ka ago, the Rungwe Pumice. The sub-Plinian Isongole Pumice eruption was dated at ca. 2 ka. Three more, smaller-scale, explosive eruptions were dated within the last 1.5 ka. From the – preserved – stratigraphic record, suggesting an eruptive frequency of at least one explosive eruption every 500 years, it is clear that Rungwe volcano was dominated at least in its late Holocene history by explosive eruptions generating pyroclastic fallout deposits. Volcanic ash fallout is therefore the most important volcanic hazard at Rungwe.

Ngozi had two major eruptions on a regional scale, the Kitulo Pumice and the Ngozi Tuff, both of which possibly contributed to the formation of its present-day collapse caldera. The ca. 10 – 12 ka Kitulo Pumice can tentatively be correlated regionally in sediment cores from RVP-surrounding rift Lakes Malawi, Rukwa and Tanganyika. Current data are consistent with a major Plinian-style eruption generating a fallout deposit covering the entire RVP. The Ngozi Tuff is the only dominantly pyroclastic flow forming eruption identified in the stratigraphic record, and happened within the last 1 ka. The Ngozi Tuff deposit suggests that Ngozi has been active until recently, and that it is capable of producing significant pyroclastic density currents especially in the valleys S of the volcano where very poor and remote villages are located. This behaviour significantly contrasts with that of Rungwe. The eruptive behaviour and frequency of Ngozi is still very poorly known and should be studied in more detail in the future.

The ca. 4 ka Plinian-style Rungwe Pumice eruption, the best preserved and most significant Rungwe eruption in its Holocene record, is closely documented and physically characterized. The comprehensive documentation of its deposit enabled to infer key eruptive parameters important to understand the hazards related to a Plinian-style eruption at Rungwe. The Rungwe Pumice is the first eruption of an African volcano to be documented and modelled in this way. The maximum eruption column height is estimated to be 30.5 – 35 km, corresponding to a mass discharge rate of $2.8 - 4.8 \times 10^8$ kg/s. The best estimate for the deposit volume is $3.2 - 5.8$ km^3 corresponding to an erupted mass of

1.1 – 2.0 x 10^{12} kg. The Rungwe Pumice has proven to be a unique scientific case study for two reasons. First, the eruption happened in nearly wind-free conditions, as evidenced by empirical and semi-analytical modelling and dispersal maps. Second, it lacks pyroclastic density current deposits which are usually found in other similar Plinian eruption deposits as a result of fountain collapse.

Despite the large volume estimate for the Rungwe Pumice, the eruption did not result in the formation of a collapse caldera. This is consistent with the existence of a fairly deep magma chamber, which has indeed been confirmed by comparison of the crystal assemblage with that of similar volcanic systems (Campi Flegrei, Italy; Tenerife, Spain). Pre-eruptive temperatures of 900 – 950°C and pressures between 140 and 175 MPa, constraining the top of the magma chamber at 5 – 6 km depth, are suggested. Further petrological evidence suggests high ascent rates, in the order of maximum 2 days, from the main magma body to the surface.

The findings presented in this thesis provide a major step forward in the understanding of processes at work in the RVP and Rungwe volcano in particular, but many questions, both scientific and hazard-related, remain unanswered. Some of the (research) efforts that are suggested could contribute to the development of the Rungwe region, as people can benefit from the rich ecosystems and natural resources offered by the volcanoes while raising awareness and planning for the good management of potential risks associated with future volcanic activity.