The geology, geochemistry and evolution of Nisyros volcano (Greece). Implications for the volcanic hazards

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Compared to Kos , Nisyros is a very small island, how is it possible there is something interesting in that isle ?... This was thinking one of us (LM) when he was approaching Nisyros fort the first time on a small boat together with the late Prof. Giorgio Marinelli. He was full professor at the University of Pisa, from 1961 to 1962; very good teacher and very bright scientist, he promoted and led several research projects on volcanology and geothermics both in Italy and abroad, including several areas along the South Aegean volcanic arc.At that time, in the '80s, Nisyros island was the site of a geothermal exploration project aimed to generate electricity. Indeed, based on the positive indications gathered through suitable surface surveys carried out by the Institute of Geological and Mineral Exploration (IGME), under the surpervision of Giorgio Marinelli, the Greek Energy Authority (PPC) decided to drill two deep geothermal wells in the southern Lakki plain of Nisyros, near the area of the hydrothermal craters. Actually, Giorgio Marinelli was aware of the high geothermal potential of Nisyros and he also understood the dynamics of the hydrothermal eruptions that occurred in this geologically fascinating place.

After some researches carried out in the early '90s on the hydrothermal eruptions and on the chemistry of fumarolic effluents and thermal waters, we decided to work together on fluid geochemistry, enriching this subject with stable isotope geochemistry and measurements of CO2 fluxes from soil and soil temperatures in the area of the hydrothermal craters. These researches were brillianty carried out first by Tatjana Brombach, in the framework of her PhD Thesis and afterwards by Jens Fiebig as part of his post-doctoral stage both at Lausanne University.

During one of the field visits together with Claudia Principe, it became evident that knowledge of Nisyros geology was far from satisfactory. First, all the previous geological maps were prepared on a merely geolithological basis. Second, the reconstruction of tephra stratigraphy and facies analysis was uncomplete. Therefore, we charged two students of Lausanne University , Loÿc Vanderkluysen and Alain Volentik, with geological mapping and related volcanological studies under the supervision of both Claudia Principe, IGG-CNR, Pisa and one of us (JCH). This work attracted more students and we ended the work with seven persons in the field.

A further weak point in the geological work previously performed on Nisyros were the scarce and not very conclusive age determinations, so that a further PhD Thesis was assigned to Annett Büttner under the supervision of Igor Villa, University of Bern. Unfortunately, we had to find out that their investigations were not adequate for elucidating the geochronology of Nisyros volcanic rocks, which is a subject deserving further careful studies.

In 1999, we started, as a full member of the European three-year project GEOWARN (Geo-spatial warning systems Nisyros volcano, Greece . An emergency case study. IST-12310), a collaboration of Greek, German, Italian and Swiss geoscientists. As work with Lausanne students had started two years prior to GEOWARN outlasting this european project, and mapping, geochemistry of rocks and minerals, and geochronology were not included and financed by the GEOWARN project, we decided to assemble all these data in the present volume of the Mémoires de Géologie (Lausanne). Partially the results have been published

in different journals but the huge amount of data backing these results merit a proper documentation in this synthesis.

The major result of volcanological investigations is a new geological map in the 1:12,500 scale, which represents the pivotal subject of this monography. Thirty-six stratigragphic units were defined, including 9 pyroclastic sequences, 16 lava flow units, 7 epiclastic units, 2 lacustrine deposits, as well as as 1 debris avalanche deposit, on the basis of their physical characters, the stratigraphic position of each deposit and the presence of discontinuities, erosional surfaces, palaeosoils and epiclastic deposits within the reconstructed stratigraphic sequence. In contrast to previous maps, this new geological map is based on the use of Unconformity Bounded Stratigraphic Units (UBSU) in compliance with the guidelines of the International Subcommission on Stratigraphic Classification. UBSU are separated by discontinuities in the stratigraphic succession, which emphasise the major breaks in the evolution of the volcano and its spatial and temporal geometry. This approach greatly improves in the understanding of the geological history of the island and highlights changes in the eruptive styles as well as the localisation of the volcanic centres through time. These topics are exhaustively discussed in chapters 2 and 3.

Further results of the volcanological investigations concerning tectonic and volcano-tectonic and petrology and rock geochemistry are presented in chapters 4 and 5, respectively, whereas the reconstructed eruptive history of Nisyros is dealt with in chapter 6. All together chapters 2 to 6 constitute the first part of the monography, which is devoted to the geological history of Nisyros volcano.

The second part of the monography has an applied component, namely the mitigation of the volcanic hazard both for the permanent residents of the island and for the annually over 50,000 visiting tourists mostly without awareness of the entire risk situation. It presents the results of a geophysical surveys (chapter 7) and of several geochemical studies (chapters 8, 9 and 10) which were carried out during the last fifteen years. Indeed, an impulse in geochemical investigations occurred during and after the increase in activity that took place in 1995-1998 comprising intense seismicity, with earthquakes of magnitudes between 4.1 to 5.5 on the Richter scale, ground deformations, as well as remarkable variations in the chemistry of fumarolic effluents. In spite of these considerable efforts of the scientific community that led to the publication of several papers, a thorough review and synthesis of the existing geochemical information was still lacking. Chapter 9 is aimed to fill this gap. The need for the stochastic approach in the evaluation of the fluxes of CO2 from soil and the total output of carbon dioxide is emphasized in chapter 8, thanks to the contribution of Marino Vetuschi Zuccolini, the first who understood the importance of this geostatistical technique, in spite of what other people claim. Chapter 10 is devoted to evaluate the timing of argillic alteration and advanced argillic alteration by using reaction path modeling and to infer possible consequences for debris avalanches induced by flank collapse and hydrothermal eruptions. Finally, the implications for mitigating the volcanic hazard at Nisyros drawn from all the geological, geophysical, and geochemical data presented and reviewed in this monography are discussed in Chapter 11.

We hope that our work may be of help for the people who live on this Earthly Paradise or just spend some time there. We would like to thank the population of Nisyros for their warm hospitality, that always turned our field seasons into wonderful experiences. Special thanks are due to Roberto Cioni of IGG-CNR, Pisa and Roberto Moretti of OV-INGV, Napoli for laboratory chemical analyses and field assistance, respectively. The internationally composed GEOWARN group contributed to the success of our work, many fruitful

discussions helped to clear our views on our proper work and also helped with many important details. Last but not least we sincerely thank Lorenz Hurni, who allowed us to use the topographic map as base of our geology.