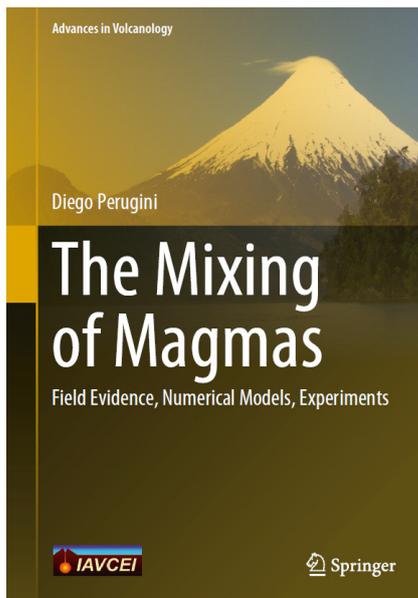


**The mixing of magmas. Field evidence, numerical models, experiments**, by Diego Perugini, 2021. *Advances in Volcanology*, Springer, Switzerland; 162 pages; eBook price 85.89 EUR, ISBN 978-3-030-81810-1.



The present tome is part of the *Advances in Volcanology* series, which is officially sponsored by the world organisation of volcanologists, IAVCEI. It is the aim of the series editor, Karoly Nemeth, to publish scientific monographs on a varied array of topics prepared by leading experts who are actively working in the relevant field. The leading expert in the present case is Diego Perugini, who informs the reader in the Acknowledgements section about the peculiar path he travelled to become an igneous petrologist. Starting out with the idea of becoming a palaeontologist, a series of encounters subsequently steered him towards geochemistry, fractals and experimental petrology. This is probably the first lesson of the present volume, and not the least significant one: close links with open and stimulating minds may lead you into innovative fields such as the construction of the prototype of a chaotic magma mixing device. This tome is skilfully divided into four parts that mark an introduction to the problem (General overview), the types of approach used (Numerical and experimental simulation of magma mixing), the strictly petrological aspects (Magma mixing: a petrological process) and the im-

plications for the study of volcanic eruptions (Magma mixing: a volcanological tool). Mixing is the process in which two magmas experience mutual chemical exchanges; unlike mingling which refers to the process of physical dispersion (no chemical exchanges are involved) of one or more magmas in another magma. Magmas can efficiently mix when their rheological behaviour are similar, which may occur at any stage of the magmatic system's life cycle when chemical gradients form. Thermal and chemical gradients are produced by fractional crystallisation, assimilation or partial melting. Mixing can be recognised in rocks by the occurrence of flow structures, magmatic enclaves or physical-chemical disequilibrium in minerals (Chapter 1). In the following two chapters, chaos theory and fractal geometry are introduced – not to worry, it is not as scary as it sounds! It is also possible to explore the exciting world of chaotic fluid mixing (Chapters 2 and 3). Why? Because Perugini wishes to provide to us the tools to grasp fully and appreciate what will be presented in the remainder of the book. Mathematical models are now being employed so as to gain fresh insights into a wide range of natural phenomena, even if they still have limitations especially when applied to complex flows. Numerical models offer pretty new ways to measure mixing processes. For example, concentration variance decay can be tracked over time, and histograms can be utilised to determine the hybrid composition of the mixing system (Chapter 4). How can scientists test their ideas about what happens inside volcanoes? One way they do this is by using physical models. These models help them check if their theories are correct, explore the different aspects of volcanic activity, and test how things might behave under extreme conditions. This is really important when studying magma and volcanic systems. Perugini describes some experiments that scientists have done with really hot and pressurised materials that are a lot like the molten rock found inside volcanoes. By using these special materials, researchers can test how different components interact and how they flow under extreme conditions, thus helping to

understand how volcanoes work in the real world. Some new apparatuses designed to perform experiments with natural melts are described in detail, such as the centrifuge to perform magma mixing experiments or the chaotic magma mixing apparatus. Experiments described were performed using natural compositions from the Phlegrean Fields volcanic area in Italy. What happens when hot, molten rock (referred to as mafic magma) is poured into a chamber that is already filled with cooler and thicker molten rock (known as felsic magma)? The experiments allow to see how the two types of magma mix and how they move around. These experiments indicate that thermal exchanges play a key role in magma mixing systems because they can trigger convection dynamics (Chapter 6). The creation of enclaves and flow structures within magma is a direct result of the various movements and interactions that take place inside. These structures are crucial in understanding the process of magma mixing, as they provide valuable insights into the dynamics and behaviour of the molten material. Thus, they serve as critical evidence of the mixing process that occurs within magmatic masses. Assuming that a period of  $10^4$  years is a possible lower limit for the thermal lifetime of a magma chamber, only enclaves with diameters smaller than twelve centimetres can be completely homogenised. By using advanced image analysis techniques, it is possible to study the flow structures present in volcanic rocks and gain insights into the mixing process that occurred. To simulate these flow structures, researchers conduct high-temperature experiments that mimic the conditions inside magmatic systems. These flow structures develop as a result of repeated stretching and folding, which may happen from the start of the mixing process until the magma solidifies and can no longer flow. When magma mixes, it can create areas with vastly different compositions, including completely homogenised regions and sections that retain their original composition. Therefore, by studying these flow structures, it is possible to understand better how magma mixing occurs and what types of compositions may result from it (Chapter 7). Mineral zoning can be generated by multiple processes possibly overlapping to the disequilibrium induced by mixing. Oscillatory zoning in crystals represents a magnificent archive of information and a formidable recorder of petrological processes to derive information on both the volcanological and petrological evolution of magmatic systems (Chapter 8). Collecting samples from mixed igneous bodies can be a challenging task, and the quality of the sampling can be greatly affected by the roughness of the terrain where the igneous

body is exposed. To ensure reliable sampling, it is important to focus on outcrop portions that have the highest roughness and avoid flat or nearly flat areas. By doing this, the quality and robustness of the samples can be significantly improved (Chapter 9). Volcanic eruptions represent the final outcome of the petrological processes that had taken place within a magma reservoir from its initial formation in the source region to its ascent to the Earth's surface. Thermodynamical and rheological modelling define the change in viscosity of a felsic magma intruded by a hot and less viscous mafic magma. The results above indicate that the felsic mass was overheated by the arrival of the mafic magma in the magma chamber. Overheating of the felsic mass may have enhanced its mobility, favouring magma ascent and eruption (Chapter 10). The primary cause of explosive volcanic eruptions is the influx of fresh magma from deeper sources that refills a subterranean magma chamber. This refilling process induces mixing between the resident and incoming magmas, leading to a time-dependent diffusion of chemical elements. The eruption can occur at any point during this mixing phase and serves to "lock in" the composition of the mixed magma. As a result, the time elapsed between the mixing and eruption is recorded in the rock's compositional patterns (Chapter 11).

Occasionally authors take the liberty to make a text more personal. This is the case when Perugini decides to include the Vesuvian eruption of 79 AD amongst the most explosive eruptions of the last two centuries (Table 10.1) and to justify this declares, "As the author was born in Italy also the catastrophic eruption of Vesuvius that occurred in A.D. 79 is included". The language of a scientific text can really make the difference between enjoyability and pedantry. Perugini chooses a simple and direct language, often peppered with anecdotes about his research and even extravagant comparisons. Perhaps the most effective and grotesque concerns the activities of petrologists, which I cannot resist but quote here: 'Volcanic rocks are like a corpse. We cannot ask a corpse what was the cause of the decease. It would simply not answer. We can perform post-mortem examinations, an autopsy. And this is what we usually do as petrologists with rocks. We collect them, we take sections, we perform analyses. And, ultimately, we propose hypotheses. But we can do much more. We can wear the clothes of Dr. Frankenstein and resuscitate volcanic rocks in the laboratory with high-temperature experiments. Sometimes we create monsters, sometimes we discover new ways to look at the complexity of Nature'.

The present volume deals with the evolution of magmas, from the zone of residence to the eruption, focusing on the process that the author believes occurs in more than 90 per cent of explosive eruptions: magma mixing. 'The mixing of magmas' is structured so as to provide not only the right and accurate information, but also the basic theoretical tools to understand the processes involved in magma mixing. The passion of the author, who has

spent many years in this field of research, is clearly seen in each chapter in which he strives not only to explain but also to create fascination about the topics covered.

*Claudio Scarpati*  
*University of Naples Federico II, Italy*  
*e-mail: claudio.scarpati@unina.it*