UNIVERSITÉ DE GENÈVE

PRESS RELEASE

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Mapping the heart of volcanoes when they wake up

A team from UNIGE and INGV has created an unprecedentedly accurate 3D model of the internal structure of an active volcano, marking an advance in risk management.

Volcanic eruptions can have dramatic consequences. But how can we anticipate this phenomenon, which unfolds up to tens of kilometres beneath the surface? A team from the University of Geneva (UNIGE), in collaboration with the National Institute of Geophysics and Volcanology (INGV) in Italy, has successfully recreated a 3D model of the interior of the Vulcano volcano, located in northern Sicily. This image, produced with unprecedented accuracy, was obtained by combining nodal seismic networks and artificial intelligence. Published in *Nature Communications*, these results represent a major breakthrough in understanding volcanic structures and, potentially, in risk management.

Our planet is home to more than 1,500 active volcanoes, yet only 30% of them are well studied by scientists. Meanwhile, over 800 million people live near these often unpredictable giants. Developing tools to better understand and anticipate eruptions is therefore a major research challenge.

"Until now, volcano seismology has primarily focused on earthquake signals beneath volcanoes. Large-scale studies have certainly helped to outline their internal structures, but very few have examined in detail what occurs deep underground," says Douglas Stumpp, a doctoral student in the Department of Earth Sciences, Earth and Environmental Sciences Section, at the Faculty of Science, UNIGE, and lead author of the study. This is due to the unique nature of each volcano and the inaccessibility of the geological domains where eruptions nucleate.

A "photograph" of unprecedented precision

Thanks to recent work by Matteo Lupi's team, associate professor in the Department of Earth Sciences, Earth and Environmental Sciences Section, Faculty of Science, UNIGE, Douglas Stumpp has produced a high-resolution, three-dimensional image of Vulcano's internal structure. Located on the eponymous island in northern Sicily, the volcano entered a phase of unrest in late 2021. The awakening was characterised by so-called "very long period" seismic events, a signal indicating the motion of magma and gas within the volcanic system.

Pictures

"We used a seismic ambient noise tomography approach, acquired by a nodal network. To process the data we used neural networks, a technology that allows us to 'x-ray' volcanoes. This work was carried out as part of the joint master's programme of the Universities of Geneva and Lausanne (ELSTE)," explains the researcher. With the support and collaboration of INGV, the team deployed around 200

portable seismic sensors across the island. For a month, these state-of-the-art seismometers recorded natural ground vibrations over a wide range of frequencies.

It is known, for example, that certain waves — known as secondary seismic waves — propagate slowly when passing through fluid-rich zones, enabling the detection of potential magma. This massive volume of data was then processed by UNIGE's supercomputer, Yggdrasil. "Ambient noise tomographic technology has been available for about 20 years, but deploying such a large number of sensors and processing their data with AI is truly novel," says Matteo Lupi, who led the study.

Thanks to this data, the team was able to precisely reconstruct Vulcano's internal structure. This modelling also reveals the distribution of magmatic fluids in its upper regions. "It is a breakthrough comparable to the transition from ultrasound to MRI in medicine," says the researcher.

From knowledge to prevention

These results do not yet allow an eruption to be predicted, but they represent a significant leap forward in understanding the internal dynamics of volcanoes. "If we could process data from seismic ambient noise nodal tomography in real time, assisted by neural networks, we could analyse the behaviour of each area of the volcanic system as it unfolds — and thus design dynamic, adaptable evacuation plans. The ultra-fast processing of such massive volumes of data remains a major technical challenge, but the integration of machine learning and deep learning, as demonstrated in this study, shows that this prospect is now becoming feasible," concludes Douglas Stumpp.

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