Cracking the code of active volcanoes

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Through the Horizon 2020-funded IMPROVE project, European scientists are deploying cutting-edge tools to reveal the hidden dynamics of Earth's most powerful forces

Volcanoes are among the most dramatic and destructive natural phenomena on Earth. But while eruptions capture headlines, the real action begins deep below the surface, often months or years before any lava breaks through. Understanding what happens inside a volcano has long been one of geoscience's most daunting challenges. Now, a team of researchers from across Europe is bringing new clarity to this underground world.

The IMPROVE project

The Horizon 2020-funded IMPROVE project brings together early-career scientists, seasoned experts, and industry partners in a coordinated effort to peer beneath the crust of active volcanoes. From Iceland to Italy and from fieldwork to computer simulations, the project is building a high-resolution picture of the structures and processes that govern volcanic systems.

At its heart, IMPROVE is about improving our ability to observe and model what we cannot see directly. Volcanoes are not simply conduits for molten rock; they are complex, ever- evolving systems where geology, chemistry, physics, and fluids interact in intricate ways. The project tackles this complexity by combining multiple scientific disciplines, including geophysics, geochemistry, numerical modelling, and engineering.

"To understand how a volcano behaves, you have to understand what's going on below the surface, and that requires data, models, and people who can speak across traditional scientific boundaries," says the project coordinator. "IMPROVE is about building that community and equipping the next generation of scientists with the tools to do just that."

One of the project's main ambitions is to advance subsurface imaging, a kind of 'X-ray vision' for the Earth's crust. By deploying techniques such as seismic tomography, magnetotellurics, gravity and ground deformation monitoring, empowered by Machine-Learning techniques, the team can map features like magma reservoirs, fluid pathways, and fracture zones that are critical to understanding volcanic behaviour. Dedicated multi-parametric field campaigns provide high-resolution data CRACKING THE CODE from arrays of appositely deployed instruments, informing analogue experiments and feeding into physical and numerical models that simulate how these systems evolve over time, both in quiet phases and during unrest.

Research focus: the Krafla and Mount Etna volcanoes

The project has focused on two high-profile volcanic systems: Krafla in Iceland and Mount Etna in Sicily, each offering unique opportunities to peer inside active volcanoes. At Krafla, a 2009 geothermal drilling operation accidentally intersected molten magma at a depth of just 2.1 kilometres. This rare event provided a precisely located magmatic body, allowing scientists to fine-tune geophysical methods for detecting and imaging magma reservoirs. In contrast, Mount Etna, one of the world's most active and closely monitored volcanoes, generates continuous streams of observational data. These data are critical for studying the physical and chemical processes that drive volcanic unrest and eruptions. New insights are emerging from signals that have gone largely overlooked in the past, as only recently, new instrumental advances and increasingly sophisticated numerical simulations combine to unlock signal frequencies that were practically unknown in the past.

By focusing on these two complementary case studies, Etna in Sicily and Krafla in Iceland, IMPROVE researchers are combining direct subsurface constraints with dynamic surface observations to unravel the inner workings of volcanic systems.

Importantly, the project is not just about academic research. By training a new generation of geoscientists through the Marie Skłodowska-Curie Innovative Training Network, IMPROVE is helping to build long-term capacity in a field that is vital for both scientific progress and public safety. The researchers are learning to work across disciplinary lines, engage with stakeholders, and translate complex science into actionable information.

IMPROVE's multi-stakeholder approach

A defining strength of IMPROVE lies in its close integration of academic research with industrial expertise. From the outset, the project has brought together universities, research institutes, energy companies, and high-tech instrument manufacturers in a collaborative framework designed to maximise mutual benefit. Among the key partners is Landsvirkjun, Iceland's national energy company, a global leader in geothermal development, whose operational experience offers invaluable real-world context to the scientific work. Instrument manufacturers, too, are actively involved in helping design, refine, and test cutting-edge sensing technologies in direct response to field needs. This tight loop between science and industry ensures that research outputs are not only innovative but also practically deployable, accelerating the path from data to application and enabling a more agile response to both energy and hazard-related challenges.

The applications go beyond eruptions. The same methods used to probe volcanoes are also critical for assessing geothermal energy potential, managing subsurface resources, and understanding natural hazards more broadly. As such, the project's impact extends to areas like sustainable energy and climate resilience.

As the climate crisis sharpens focus on natural hazards and renewable energy, the kind of integrated, collaborative science championed by IMPROVE is more important than ever. Volcanoes are extremely complex systems, but with better data and models, scientists are getting closer to decoding their signals and giving society more time to prepare.

The outcomes of the IMPROVE project will help shape both science and policy regarding volcanic risk. The new insights generated by the project, alongside its open data tools, training programmes, and cross-sector partnerships, are laying the groundwork for a more informed and resilient response to volcanic activity across Europe and beyond. Because in the end, understanding what lies beneath isn't just a scientific quest; it's a matter of safety, sustainability, and global responsibility.

IMPROVE ("Innovative Multi-disciplinary European Research training network on VolcanoEs", https://www.improve-etn.eu) is a European Union's Horizon 2020 Marie Sklodowska-Curie European Training Network (grant agreement No 858092). There are nine academic partners and three industrial partners in the project.

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