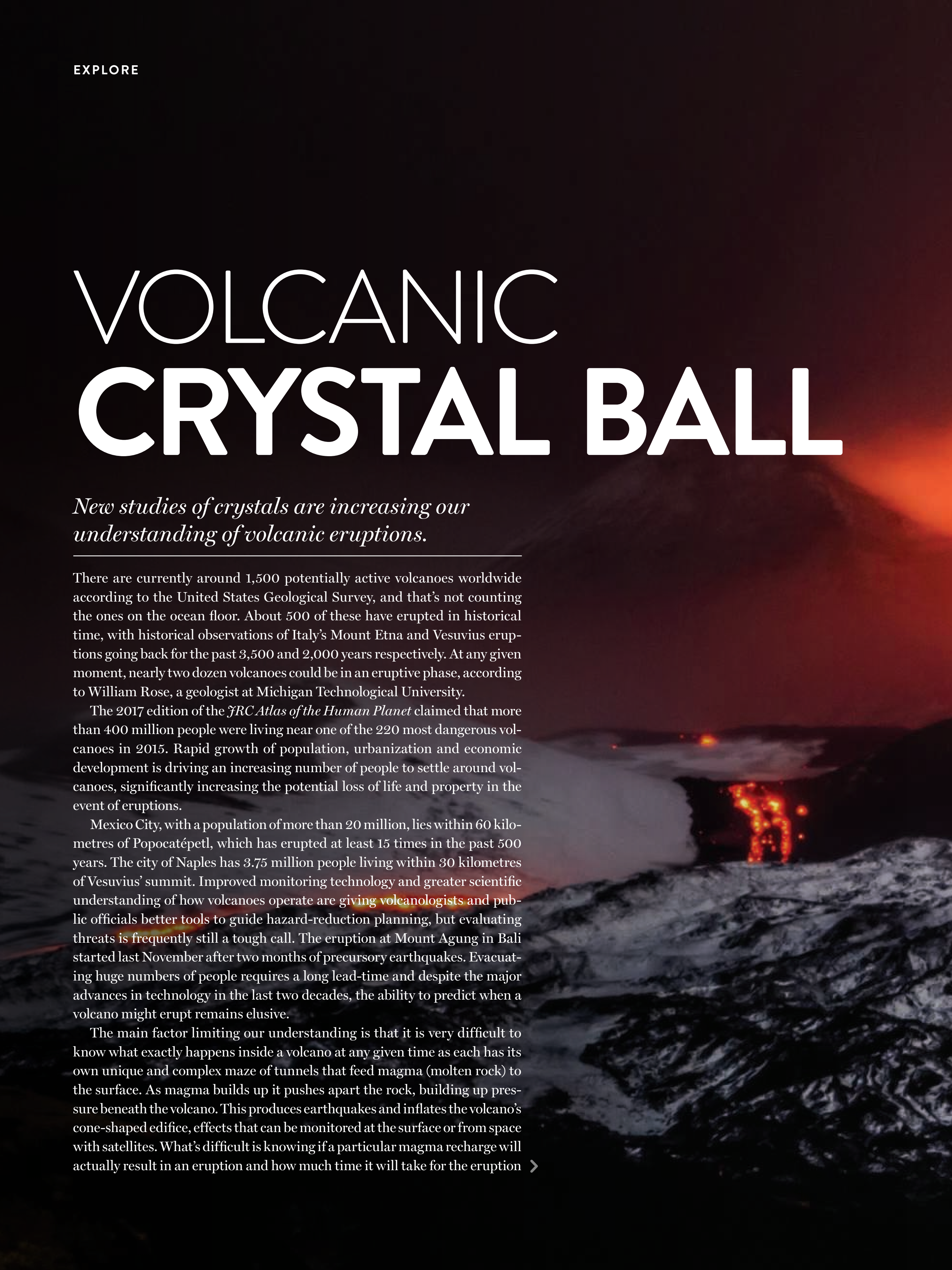


VOLCANIC CRYSTAL BALL

New studies of crystals are increasing our understanding of volcanic eruptions.

There are currently around 1,500 potentially active volcanoes worldwide according to the United States Geological Survey, and that's not counting the ones on the ocean floor. About 500 of these have erupted in historical time, with historical observations of Italy's Mount Etna and Vesuvius eruptions going back for the past 3,500 and 2,000 years respectively. At any given moment, nearly two dozen volcanoes could be in an eruptive phase, according to William Rose, a geologist at Michigan Technological University.

The 2017 edition of the *JRC Atlas of the Human Planet* claimed that more than 400 million people were living near one of the 220 most dangerous volcanoes in 2015. Rapid growth of population, urbanization and economic development is driving an increasing number of people to settle around volcanoes, significantly increasing the potential loss of life and property in the event of eruptions.

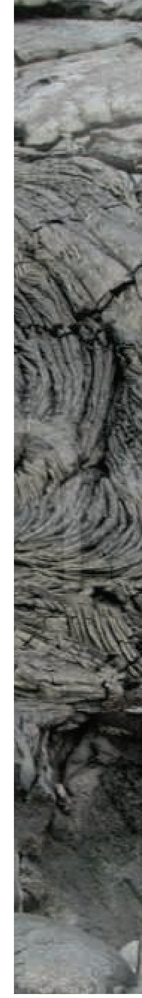
Mexico City, with a population of more than 20 million, lies within 60 kilometres of Popocatépetl, which has erupted at least 15 times in the past 500 years. The city of Naples has 3.75 million people living within 30 kilometres of Vesuvius' summit. Improved monitoring technology and greater scientific understanding of how volcanoes operate are giving volcanologists and public officials better tools to guide hazard-reduction planning, but evaluating threats is frequently still a tough call. The eruption at Mount Agung in Bali started last November after two months of precursory earthquakes. Evacuating huge numbers of people requires a long lead-time and despite the major advances in technology in the last two decades, the ability to predict when a volcano might erupt remains elusive.

The main factor limiting our understanding is that it is very difficult to know what exactly happens inside a volcano at any given time as each has its own unique and complex maze of tunnels that feed magma (molten rock) to the surface. As magma builds up it pushes apart the rock, building up pressure beneath the volcano. This produces earthquakes and inflates the volcano's cone-shaped edifice, effects that can be monitored at the surface or from space with satellites. What's difficult is knowing if a particular magma recharge will actually result in an eruption and how much time it will take for the eruption

Mount Etna
erupts in 2013

Above and above right: Geoscientists Kari Cooper and Christy Till

Right: Balz Kamber, Chair of Geology and Mineralogy at Trinity College, Dublin



to start. However, that is starting to change thanks to scientific breakthroughs focusing on volcanic crystals.

INTERPRETATION

Geoscientists Kari Cooper and Christy Till published a study in the journal *Science* last year that focused on zircon crystals from debris deposited around New Zealand's Mount Tarawera. By studying trace elements in the crystals, the scientists could determine when the crystals formed and how long they had been exposed to high heat (more than 700°C). Of seven crystals from Mount Tarawera studied, six were found to have been at least tens of thousands of years old, yet they spent less than 4% of that time exposed to molten magma.

The research team concluded that solid or crystalline magma (below 650°C) must interact with hotter liquid stored elsewhere in the volcano's reservoir in order to melt and become mobile, which creates the conditions for an eruption. Once temperatures reached 750°C, it was decades or less before an eruption occurred.

The crystals are like a 'black box' flight recorder for studying volcanic eruptions, according to Dr Cooper. "The crystals can tell us what was going on while they were below the surface, including the run-up to an eruption."

This pattern of long-term crystal storage in almost solid magma, punctuated by rapid heating, was found to be applicable to many other volcanoes around the world. This means scientists now have a better understanding of when a long dormant volcano is likely to erupt.

Till believes their findings will have a significant impact on volcanology. "Our idea of how the magma reservoir below a volcano behaves has evolved a lot over the last 10 or 15 years," she said.

"To understand volcanic eruptions, we need to be able to decipher signals the volcano gives us before it erupts," says Jennifer Wade, a Programme Director in the National Science Foundation's Division of Earth Sciences, which funded the research. "This study backs up the clock to the time before an eruption and uses signals in crystals to understand when magma goes from being stored to being mobilized for an eruption."

Balz Kamber, Chair of Geology and Mineralogy at Trinity College, Dublin, and Teresa Ubide, Lecturer in Igneous Petrology/Volcanology at the University of Queensland, also focused on volcanic crystals in a study released this year.

When new volcanic magma flows into an existing underground reservoir – usually about 30 kilometres beneath a volcano – it catalyses chemical reactions in trachybasalt (a type of basalt rock), which creates clinopyroxene crystals. As those crystals cool, they leave a record of certain aspects of their immediate environment, including forming rings in response to

Above: New Zealand's Mount Tarawera

Left: Magma (molten rock)

the presence of magma. Using those rings, Professor Kamber and Dr Ubide are able to estimate the depth at which new magma is present and determine how soon a volcanic eruption might take place. They found that when new magma arrives at the 30-kilometre depth, a volcanic eruption occurs within a couple of weeks about 90% of the time.

Professor Kamber and Dr Ubide focused on tiny trace elements, notably chromium, which generates distinctive images depending on the stage of development.

The scientists exposed the crystals to a process known as Laser Ablation-Inductively Coupled Plasma Mass Spectrometry (LAICPMS) to accurately measure chromium traces within them. They then coupled the data with that obtained from a process called thermobarometry, in which minerals found within volcanic rock can be used to trace its history of temperature and pressure changes.

This process is used to create a 2D image of the crystal's composition that can tell us something about its history. For example, when old clinopyroxene cores are transported to the surface by newly stirred magma, it generates a distinctive rim on the crystal. The challenge is to extract meaning from these records.

"What we discovered is that the crystals contain a memory in the form of growth layers that look similar to tree rings. Reading the history from these layers may lead to more effective volcanic hazard monitoring, including the likelihood of dormant volcanoes becoming active," Professor Kamber explained.

Dr Ubide noted: "Knowledge on the typical mechanisms triggering past eruptions, the depth at which they occur and the lead times to eruption could advise future volcano monitoring efforts. The crystal record could provide new insights on the hazard potential of future earthquake signals and the time available for emergency planning."

Their research, when combined with monitoring of small nearby earthquakes and indication of depth where the growth path is occurring, adds up to a "powerful tool" to predict what is likely to happen and when.

To make their finding, the researchers examined clinopyroxene crystals ejected from Mount Etna in Italy during a spate of eruptions that occurred between 1974 and 2014. They are now planning to expand the approach to other volcanoes around the world, and to combine the information with geophysical signs of magma movement.

The scientists say that further research is needed, particularly in order to better understand the growth rates of clinopyroxene. This, in turn, will likely lead to an improved understanding of magma behaviour, permitting, hopefully, more accurate eruption forecasting.

"We haven't yet reached the 'holy grail' of being able to predict volcanic eruptions, but our research is a significant step forward in understanding the processes that lead to eruption," concluded Dr Ubide.