A tale of two kinds of volcanoes

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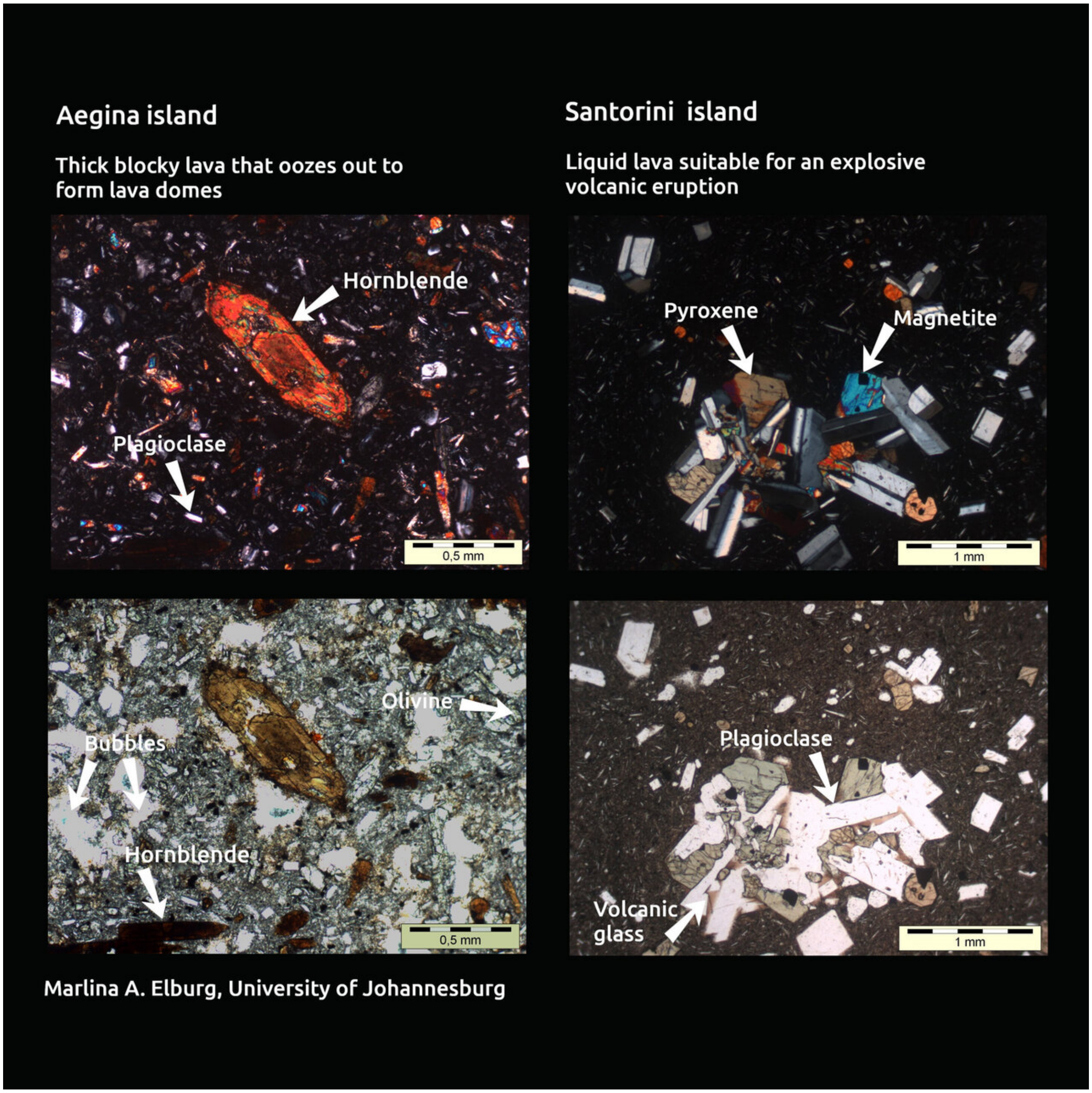


Why a big volcanic blow-up at the popular travel destination Santorini 3200 years ago, but just a few hundred kilometers away, no drama at the volcanoes on Aegina , Methana and Poros islands? Thin sections of the lavas from these four volcanoes yield some of the reasons why. Some minerals only form at greater depths - and the hornblende in the lava from Aegina island indicates that the magma chambers there are deeper than the those underneath the Santorini caldera. But plate tectonics add another, hidden reason also, found research from the University of Johannesburg. Credit: Prof Marlina A. Elburg, University of Johannesburg

At an idyllic island in the Mediterranean Sea, ocean covers up the site of a vast volcanic explosion from 3200 years ago. A few hundred kilometers north-west, three other islands still have their volcanic histories from a few million years ago mostly intact. No explosions there. So why the differences between the Santorini caldera and the Aegina, Methana and Poros lava domes? Researchers used volcanic "fingerprints' and plate tectonics research to find out why.

The end of a civilisation

A big volcano blew up about 3200 years ago, right next to where Santorini island is in Greece today. During that eruption, liquid molten rock under the ground (magma) built up immense pressure, and then erupted into a lava explosion. The impact was so intense that the volcano collapsed into a huge basin called a caldera.

What had been an island-volcano, was then overrun by ocean, an event considered partially responsible for the demise of the Minoan civilisation.

Santorini Island became a popular travel destination with big ocean-going ships sailing over the caldera. The village of Phira perches on the cliff-edge of the remains of the volcano.

As idyllic as it looks, the Santorini volcano underneath the ocean still constitutes the biggest volcanic hazard for Europe, together with the Vesuvius volcano in Italy.

Toothpaste rather than fireworks

A few hundred kilometers north-west of Santorini, in Greece's Saronic Gulf, much closer to Athens, a completely different kind of "volcano" looks much less dramatic.

The small islands of Aegina, Methana and Poros sport rounded hills with roads winding uphill in hairpin bends. These hills have volcanic ancestry too—but they are nothing like Santorini.

Here, liquid lava didn't explode in a big eruption.

"There is no evidence that that large dramatic events ever took place at these islands," says Prof Marlina A. Elburg, a Geology researcher at the University of Johannesburg.

"Thick blocky lava oozed out of magma chambers under the ground at these islands between 5.3 to 2.6 million years ago, during the Pliocene. The lava was so thick, it was more like toothpaste or putty than liquid. It formed lava domes rather than lava volcanoes.

"After a few million years' worth of weathering, they're well camouflaged hills, but they are still considered volcanically active," she says.

How is it possible that volcanoes so close in geological time and space can behave to differently? The researchers used several techniques to find out.

Finding volcanic 'fingerprints'

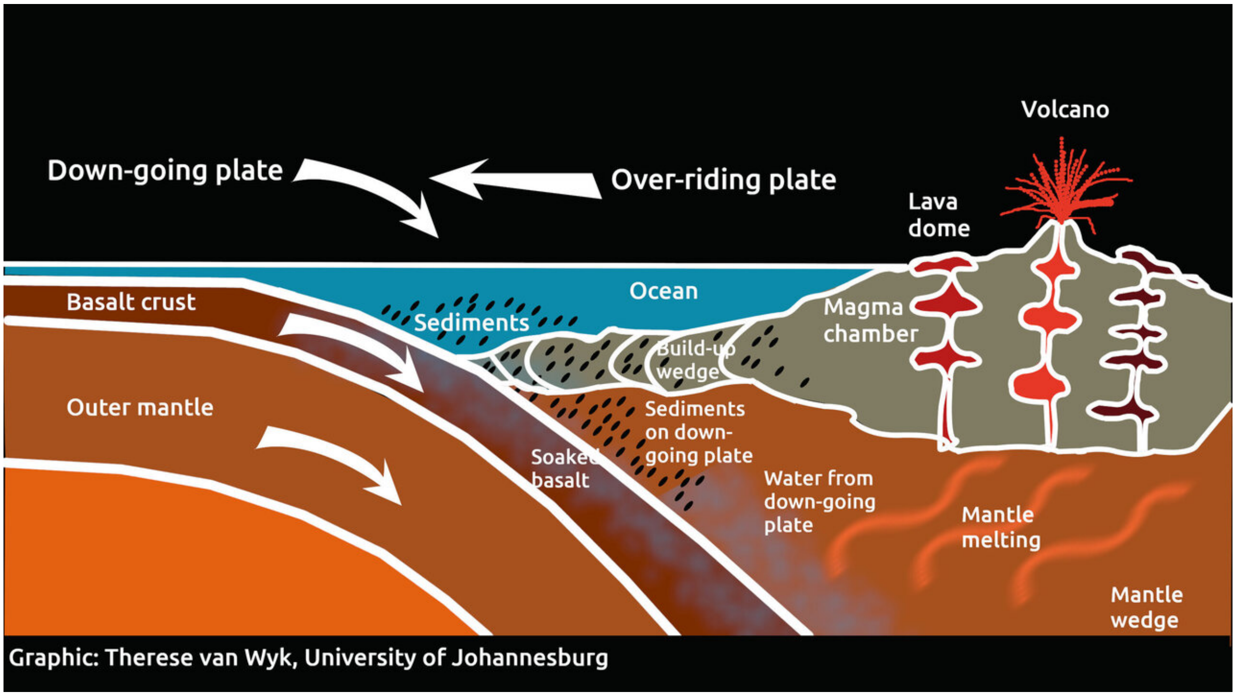
Elburg and co-author Ingrid Smet, a Ph.D. candidate at the time, analysed samples of the lavas in new whole rock analyses, in research published in *Lithos*.

The study followed on their previous research on the lavas at Methana, also published in *Lithos*.

They looked for the ratios of very specific elements in the samples, called isotope signatures. Isotope signatures work similar to 'fingerprints' for lavas—they help researchers figure out what the lavas were made of, where, and when they were formed.

"Mostly the isotope signatures matched what one would expect from where the islands are located in the Aegean volcanic arc," says Elburg.

But there were surprises too.



Why a big volcanic blow-up at the popular travel destimation Santorini 3200 years ago, but just a few hundred kilometers away, no drama at the volcanoes on Aegina , Methana and Poros islands? These islands sit on the edge of the same tectonic plate, so one could expect similar volcanic behaviour. But they have individual histories. Research from the University of Johannesburg delves into the lava mix ingredients and plate tectonics to figure out the differences. Credit: Ms Therese van Wyk, University of Johannesburg

Subterranean recycling machine

Underneath all these volcanoes at Aegina, Methana, Poros and Santorini, something else is going on in deep inside the crust of planet Earth. Running roughly east to west underneath the Mediterranean Sea is the Aegean volcanic arc. This arc is where the African tectonic plate 'dives under' the Aegean microplate.

The 'diving under' process is called subduction by geologists. It means that one part of the cool outer crust of Earth starts moving underneath another part of the crust, getting 'recycled' inside the hot liquid rock of the Earth's mantle.

The islands of Aegina, Methana, Poros and Santorini are not just islands with volcanoes. All of them are an integral part of Earth's 'recycling machine' that keeps renewing the crust underneath the planet's oceans.

This raises the question: Why do these islands have such different 'lava histories', even though all of them are on the edge of the Aegean plate?

Some of the answers have to do with what goes into the lava "mixes" for the volcanoes.

Variable lava mix recipes

The African plate 'dives under' the Aegean plate in an oceanic trench in the Mediterranean Sea. This happens very slowly at a few centimeters per year. Which means the pristine cold basalt of the down-going African plate's crust has been soaking in ocean water for millions of years before it enters the much warmer magma underneath the over-riding Aegean plate.

"The crust of the down-going plate now consists of altered rocks, containing minerals with water in them. These minerals become unstable during subduction because of the increasing pressure and temperature, and release their water," says Elburg.

"This water lowers the melting point of the mantle, similar to what happens when adding salt to ice. That is why the mantle under the over-riding starts to melt. It is this molten material, or magma, that flows/oozes out of volcanoes/lava domes as lava."

Another possible ingredient of the differing lavas is sediments in the oceanic trench at the subduction zone. At the Aegean Arc the down-going plate is covered by a very thick pile of ocean sediments. Some of the sediment is former continental crust.

A lot of this sediment is 'scraped off' when the plate subducts and forms an accretionary (or build-up) wedge. However, some of it is also going down into the mantle and getting mixed with the melting mantle wedge, she says.

Same plate, different lavas

Since Aegina, Methana, Poros and Santorini volcanoes are all part of the same subduction zone, the different volcanic activity raises several big questions. One of these is:

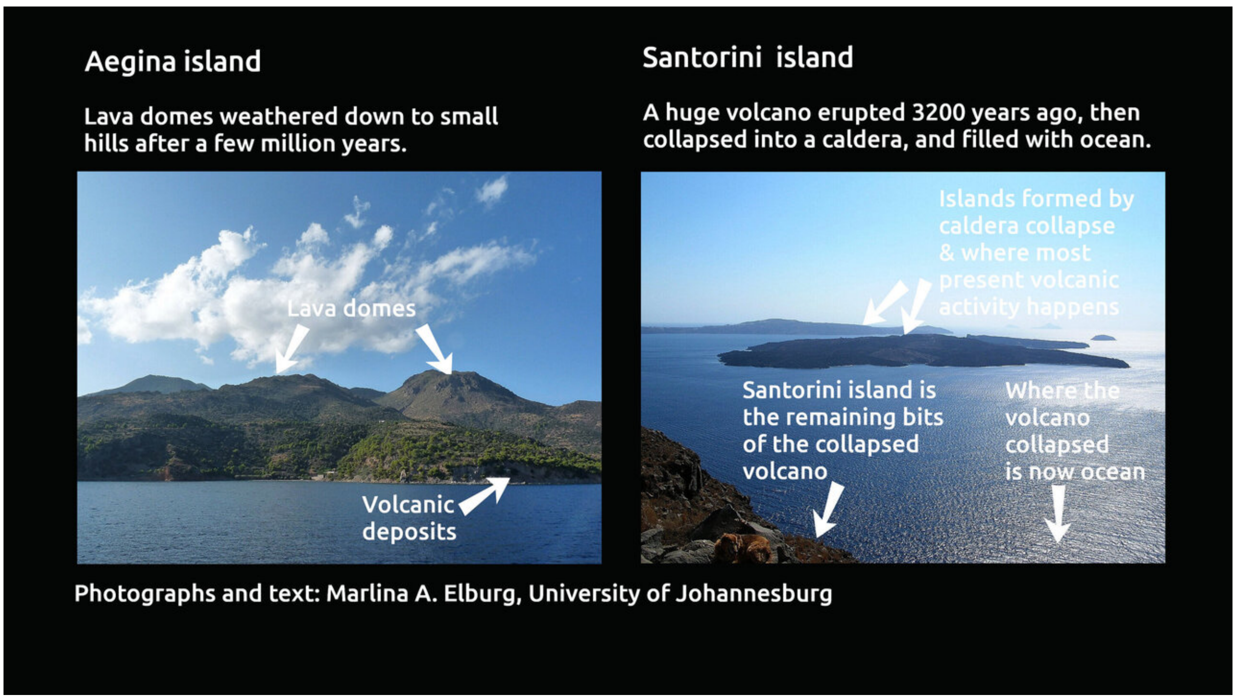
Why the thick blocky lava at the western volcanic centres Aegina, Methana and Poros 2.5 to 2 million years ago, but liquid lava at Santorini 3,200 years ago?

The answers to this creates other questions about the recycling behaviour of the planet we live on.

But subduction zones are tricky to study. It's not possible to go to one of those and come back with some sample materials. Scientists still need more understanding of what role the overriding plate plays; how much interaction there is between ascending magmas and the crust they ascend through; and whether subduction-related magmas obtain their geochemical signature from the sediment that is recycled back into the earth, says Elburg.

"The answers to these questions can help us understand to what extent the melting processes that started at more than 100 kilometers deep in the mantle, continue when the magma is closer to the surface of the earth," she says.

"This process of 'crustal contamination' is yet another 'Earth recycling machine', which may also influence the potential for ore deposits—like in the Andes, where major copper deposits are found, and where this 'intracrustal recycling' is thought to play an important role".



Why a big volcanic blow-up at the popular travel destination Santorini 3200 years ago, but just a few hundred kilometers away, no drama at the volcanoes on Aegina , Methana and Poros islands? At Santorini, the explosion was so intense, the volcano collapsed into a caldera and filled up with ocean. But the other islands have had no such drama. How can volcanoes so close in geological time and space behave so differently? Research from the University of Johannesburg uses lava 'fingerprints' and more to find out why. Credit: Prof Marlina A. Elburg, University of Johannesburg

Deeper vs shallower

One way of studying lavas is to put thin slices (called thin sections) under a microscope and identify the minerals. Because minerals need different conditions to form, their presence can say a lot about where and how magmas were mixed.

In this study the minerals indicated that Santorini lavas were more liquid because they formed at inside shallower magma chambers, while the western volcanic centre lavas were thicker and more blocky because they formed in deeper magma chambers.

"The thin sections of the Santorini lavas display pyroxenes and significant plagioclase. This indicates that the magma from which the crystals formed was located at shallow depths in the earth," says Elburg.

And there is an invisible reason the magma was at shallower depths at Santorini.

"The tectonic plate above Santorini's magma chambers is being pulled apart. In geology terms, it is under localised extension. And because the plate is being stretched out and Santorini is in the middle of it, Santorini happens to be at the thinnest part of the plate.

"With a magma chamber at a shallower depth, the roof will cave in when the chamber starts emptying itself during an eruption. This makes the eruption even worse and creates a caldera, as at Santorini," she adds.

No explosions

In contrast, when they looked at the thin sections of the thick blocky lavas from Aegina and Methana, they found hornblende. The mineral was absent in the Santorini lavas.

Hornblende can only form if the magma is deep enough in the Earth. This indicates that the magma chambers on Aegina and Methana should be located deeper than on Santorini.

"With the magma chambers at greater depths for the western Aegina-Methana-Poros volcanoes, that makes for changes in the lava. There the magma chambers underneath the lava domes did not cave in. Additionally, the crystallization of the amphibole mineral group that includes hornblende, makes magma more viscous, or sticky. So it is more difficult for the magma to come to the surface in the first place.

Over-riding plate vs sediment

To figure out whether the over-riding plate or the ocean sediments were the bigger factor in creating thick blocky lavas, the researchers analysed specific 'lava fingerprints'. These radiogenic isotope ratios gave them the best indication on which materials were mixed into the underground magmas for those lavas.

"We compared Santorini with Aegina-Poros-Methana lavas in terms of their geochemistry on $^{87}Sr/^{86}Sr$, $^{143}Nd/^{144}Nd$ and $^{208}Pb/^{204}Pb$. They were distinctly different. Then by combining the radiogenic isotope signature of the lavas with trace element ratios, we managed to pinpoint the down-going sediment as the biggest influence creating thick blocky lavas, not the overriding plate.

No one lava size

"We found that Aegina and Methana-Poros have their own individual volcanic histories, even though they're part of the Aegean arc.

"This means that a simple one-size-fits-all explanation, based on crustal contamination history, for the difference in eruptive style compared to Santorini does not work.

"Modern subduction zones are not all alike. Even in one volcanic arc, more than one eruptive style points to differences in subduction processes," concludes Elburg.

More information: Marlina A. Elburg et al, Geochemistry of lavas from Aegina and Poros (Aegean Arc, Greece): Distinguishing upper crustal contamination and source contamination in the Saronic Gulf area, *Lithos* (2020). DOI: 10.1016/j.lithos.2020.105416

Provided by University of Johannesburg

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