The oxidation of volcanoes—a magma opus

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A new, Yale-led study unlocks the science behind a key ingredient—namely oxygen—in some of the world's most violent volcanoes.

The research offers a new model for understanding the oxidation state of arc magmas, the lavas that form some volcanoes, such as the one that erupted dramatically in Tonga earlier this year.

The plume from Tonga's underwater volcanic eruption on Jan. 15 rose 36 miles into the air. Ash from the volcano reached the mesosphere, Earth's third layer of atmosphere.

"These eruptions occur in volcanic arcs, such as the Aleutian island chain, which are well known in the circum-Pacific region and produce the world's most explosive volcanic eruptions," said Jay Ague, the Henry Barnard Davis Memorial Professor of Earth & Planetary Sciences at Yale.

Ague is first author of the new study, published in the journal *Nature Geoscience*. Ague is also curator-in-charge of mineralogy and meteoritics for the Yale Peabody Museum of Natural History.

Scientists have long known that arc magmas have a higher oxidation state than rocks in most of the Earth's mantle (its upper, rocky layer). This is surprising, they say, because arc magmas form in the mantle. There has been no consensus on the origins of the oxidizing signature.

Ague and his colleagues say the process begins with a layer of sediment that covers tectonic plates beneath the ocean floor. Tectonic plates are large slabs of rock that jockey for position in the Earth's crust and upper mantle.

The sediment covering these ocean plates is largely made up of weathered materials shed from continents or produced as a result of seafloor hydrothermal vent activity. Giant tube worms and other exotic sea creatures commonly thrive near these vents. But regardless of origin, the sediments covering oceanic plates are often highly oxidized.

Tectonic plates are constantly in motion, moving at about the rate that fingernails grow. Oceanic plates are generated at mid-ocean ridges and sink sharply into Earth's interior—in a process called subduction.

That's where things get interesting for arc volcanism, Ague said.

When an ocean plate subducts, Ague explained, it heats up, is compressed, and begins to dehydrate. This metamorphism produces hot, water-rich fluids that rise toward the surface.

As these materials move upward through the oxidized sediment layer on top of slabs, the fluids themselves become oxidized—setting the stage for an arc magma.

"As the fluids continue to rise they leave the slab behind and enter Earth's mantle," Ague said. "There, the fluids drive mantle melting, producing oxidized magmas that ascend and can ultimately erupt as lava from volcanoes."

Beyond the dramatic effects of volcanic eruptions, the oxidized character of arc magmas is also geologically significant, Ague said. Oxidation is critical for making certain kinds of ore deposits, particularly copper and gold, such as those found in western South America.

Also, the injection of highly-oxidized, sulfur-bearing gases into the atmosphere after an eruption can lead to transient global cooling of the troposphere, the lowest level of Earth's atmosphere.

"This was the case with the 1991 eruption of Mount Pinatubo in the Philippines," Ague said. "It also occurred in a number of famous historical cases, such Mount Tambora in Indonesia in 1815. That was the most powerful volcanic eruption in human history and led to the socalled 'Year Without a Summer' in 1816."

Santiago Tassara, a Bateman Postdoctoral Associate in Yale's Department of Earth & Planetary Sciences, is a co-author of the new study. Other co-authors include researchers from Cornell University, the Chinese Academy of Sciences, the National Museum of Natural History at the Smithsonian Institution, Freie Universität Berlin, and the University of Crete.

More information: Jay Ague, Slab-derived devolatilization fluids oxidized by subducted metasedimentary rocks, *Nature Geoscience* (2022). DOI: 10.1038/s41561-022-00904-7. www.nature.com/articles/s41561-022-00904-7

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