Volcanic eruptions: From ionosphere to the plumbing system

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Volcanic eruptions can have global consequences on the environment, climate and humans. Volcanic plumes, composed of ash and gases, produced during explosive eruptions, can rise many kilometers above the eruptive vent to reach the stratosphere where they can be dispersed globally by the atmospheric circulation. The ash cloud produced by the 1991 Pinatubo eruption in the Philippines, for example, circumnavigated the entire globe in less than a month (Oppenheimer, 2012, and references therein).

Large volcanic eruptions inject a substantial amount of sulfur gas and ash particles into the stratosphere (Fig. 1), a large part of which disappear within a few days, but the rest of which are transformed into a mixture of sulfurous acid and water in the form of minute particles. These can stay in the stratosphere for up to one year after the eruption, causing optical effects and scattering solar radiation, which in turn has a cooling effect on the climate (Robock, 2000).

A tropical eruption enhances the pole-to-equator temperature gradient especially in the Northern Hemisphere. When the volcanic aerosol reacts with anthropogenic chlorine, it also creates a chemical effect which contributes to the destruction of stratospheric ozone (Robock, 2000). During the Mount Pinatubo eruption a total of ~20 million tons of sulfur dioxide were injected in the stratosphere and caused a drop in the air temperature of 0.5 °C during the period 1991–1993 (Oppenheimer, 2012).

Our knowledge of the causal effect between volcanic eruptions and climate cooling (Robock, 2000; Self, 2005) has significantly increased since the 1991 eruption of Pinatubo, and we now know that large eruptions in the tropics and at high latitude were responsible for interannual-to-decadal temperature variability in the Northern Hemisphere during the past ~2,500 years (Sigl et al., 2015), which in turn had a global impact on world history (e.g., Oppenheimer, 2015; Sigl et al., 2015; Luterbacher and Pfister, 2015; Pyle, 2017).

The long-range consequences of the 1815 eruption of Mount Tambora (Indonesia), or those of the 1883 eruption of Krakatau (Indonesia), are described in several publications, both scientific and science-related. Tambora’s eruption was responsible for unusually cold and rainy weather, particularly during the summer of 1816, which is known as the “year without summer.” This had devastating consequences, causing crop failures that induced a severe famine in Europe, Asia, the eastern United States and Canada (e.g., Oppenheimer, 2012; Oppenheimer, 2015; Luterbacher and Pfister, 2015; Pyle, 2017).

There is also a claim that the defeat of Emperor Napoleon Bonaparte in the battle of Waterloo (18 June 1815) by the British–Prussian Coalition led by the Duke of Wellington can be partly attributed to the eruption of Tambora. The extremely and unusually wet weather made the battlefield a pool of mud, which delayed the start of the battle, allowing the union of Prussian and Anglo-Dutch forces. As Victor Hugo put it in Les Misérables: “Had it not rained on the night of 17/18th June 1815, the future of Europe would have been different... an unseasonably clouded sky sufficed to bring about the collapse of a World” (cit. in Wheeler and Demarée, 2005). This is an unproven claim, but it is possible that an obscure (at the time) volcano might have played a large part in the history of Europe and the human race.

In this issue of Geology, Genge (2018, p. 835) explores the less well-known interaction of large volcanic eruptions with the ionosphere. Few studies (de Ragone et al., 2004, and references therein) have explored the disturbance effect that the sudden injection of energy and momentum, during volcanic eruptions, into the atmosphere can cause on the ionosphere. Any sudden powerful blast (such as a volcanic eruption, strong earthquake or even nuclear blast) can potentially trigger an acoustic gravity wave, which propagates with a frequency longer than a normal acoustic wave (Ripepe et al., 2016 and reference therein), and is capable of perturbing the atmosphere with different effects depending on the altitude (de Ragone et al., 2004). Here, Genge suggests that electric charges from volcanic plumes can cause electrostatic levitation of volcanic ash, injecting volcanic particles <500 nm in diameter into the ionosphere, disturbing the atmosphere global electric circuit on timescales of 100 s.

The immediate consequence of the injection of charged dust into the ionosphere is a sudden disturbance of climate and, in particular, the short-term formation of volcanic clouds with decreasing cloud cover and precipitation in distal areas, contrasting with increased precipitation in the vicinity of the eruption plume. The global suppression of cloud formation would increase atmospheric H2O content favoring enhanced cloud cover and precipitation in the immediate aftermath of a supervolcano eruption when the ionosphere recovers the normal behavior. Genge explores a new, and somewhat controversial, angle offering a counterintuitive suggestion that a sudden effect on climate (temperature drop, immediate cloud and rain suppression in distal areas, shortly followed by enhanced precipitation, and associated with augmented rain precipitation in the vicinity of...
the eruptive vent) can occur almost immediately during the eruption and for a few weeks after. As Genge argues, this may offer an explanation for the unusually wet weather in Europe only a month after Tambora’s eruption coeval with the last battle of Emperor Bonaparte.

Abundant rain is common during or immediately after a volcanic eruption and is often associated with devastating and deadly lahars—mudflows produced by heavy rain that remobilize the unconsolidated pyroclastic material on the flank of the volcano. Syn-eruptive lahars have been observed at several volcanoes, including Chaiten (Chile) during the 2008 eruption (Lara, 2009) and Pinatubo associated with the 1991 eruption (Newhall and Solidum, 2015). In both cases, the heavy rain was attributed to the precipitation characteristics of the region. However, the suggestion of Genge’s study that a sudden, very short-term effect on climate might be commonly associated with a very large volcanic eruption might be important when evaluating volcanic hazards at supervolcanoes, and it is an avenue that might be worth exploring. In fact, according to Genge (2018), plume charge and electrostatic levitation also increase with eruption magnitude.

Ultimately, the potential for climate forcing by volcanic eruptions depends on the size of the volcanic plume and thus the volatile content, composition of the magma, and the ejected volume, which in turn modulates eruption magnitude. Assessing the eruption magnitude and type of the next eruption at a given volcano is one of the current challenges of volcanology. This is not an easy task, even at well-known volcanoes. A multidisciplinary effort is necessary, incorporating data from a variety of observations, starting from the essential and fundamental constant real-time monitoring of a single volcano to the equally essential and fundamental forensic approach, that permits a glimpse into the possible future scenarios of activity by learning from the past eruptive history of the volcano.

The petrology community (i.e., scientists that study formation of the rocks) has achieved a remarkable understanding of the complex plumbing system that fuels a volcano. We now know that beneath a volcano, there is no such a thing as a large pond of magma, but a complex plumbing system where crystals and melt are stored in different pockets and at different levels in a semi-solid state, called crystal mush, with low melt fraction, and that can be remobilized at different but usually short timescales (e.g., Bachmann and Bergantz, 2008; Cooper and Kent, 2014; Cashman et al., 2017). By studying the minerals forming the rocks erupted from a volcano, we are able to understand how and on which sort of timescales the crystal mush is remobilized and magma accumulated before eruption (e.g., Costa et al., 2008; Drütt et al., 2012; Kilgour et al., 2014; Cooper, 2017; Petrone et al., 2018), which is an important piece of information to evaluate volcanic hazards assessment. We have made substantial progress in our understanding of magmatic processes leading to different types and size of eruptions, but there is still a lot of work to do.

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Printed in USA