DE BELLO VULCANICO or On The Volcanic War:

40-year scientific effort since May 18, 1980 eruption of Mt St Helens

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Observo experior praedico (“observe, explore, and predict”) is what USGS volcanologists successfully conducted forty years ago: they deciphered two-month series of precursory signs of earthquakes, steam-venting episodes, and volcano edifice deformation that were inferred to be the cause of magma injection at shallow depth below Mt St Helens volcano (WA, US) in 1980, after about 120 years of quiescence (Fig. 1). All these precursors helped indicate that an imminent eruption was due. This should have led to claim a caesarean *veni vidi vici* (“I came, I saw, I won”) to predict the climactic eruption event and evacuate the local population prior to the disaster. But still 57 people lost their lives (including USGS volcanologist David A. Johnston) in one of the largest eruptions of the last century, which scattered volcanic ash across a dozen states in the US, produced shockwaves and pyroclastic flows across the surrounding landscape, flattened the forests nearby, melted snow and ice, and generated massive mudflows following the collapse of the northern portion of the volcano edifice.

After 40 years since the eruption of Mt St Helens of May 18, 1980, volcanologists strive to forecast the likelihood, magnitude, and style of eruptions. In the last year, volcanoes Fuego (Guatemala), Anak Krakatau (Indonesia), Stromboli (Italy), and Whakaari/White Island (New Zealand) erupted violently with unpredicted eruption style and magnitude, resulting in the death of hundreds of people, as well as severe damage to key infrastructures of millions of dollars. Anticipating the magnitude of future eruptions (i.e., mass of erupted magma) is a vital piece of information for ~800 million people living near ~550 active volcanoes worldwide, but remains extremely challenging. More than half of the world's active volcanoes are not monitored instrumentally. Hence, even eruptions that could have rung an alarm can occur without people at risk having a clue of the upcoming disaster. This is why modern volcanology is key to thriving 21st-century societies aiming to understand geological processes such as volcanic activity that modulates the Earth's atmosphere composition and climate, can either maintain or perturb biotic equilibria, favour volcanic winters by raising the Earth's albedo and cooling its troposphere, and cause disruption to aviation, telecommunications, and water networks.

In the last 40 years, the international volcanology community has largely contributed to the overall scientific commentary of DE BELLO VULCANICO ("On The Volcanic War") by facing two major battlefronts:

1) Deciphering the volcanic precursors

To date, the recent development in technological monitoring of active volcanoes using ground-, air-, and space-borne sensors that measure ground deformation and gas emissions from volcanoes worldwide (provides essential insights on the potential of a volcano to erupt and, eventually, on the intensity of an eruption following a period of unrest. Measurements of volcano deformation permit to deduce the size and shape of the magma source at depth using geometric models, and show that volcanoes can experience either deformation or no deformation prior to their eruption. The cryptic causes of these variations prevent volcanologists from using the amount of deformation to predict the volume of magma that is finally erupted. Satellites easily detect in real time volcanic SO_2 emissions in the ultraviolet and infrared observational spectrum. If one compares the released amount of volcanic SO_2 and the corresponding volume of erupted magma, there is an evident disparity between the two parameters, which also affects the eruption style: volcanoes with SO_2 excess have an explosive character, whereas volcanoes with SO_2 deficiency have effusive activity. This disparity prevents volcanologists from forecasting the amount of SO_2 released into the atmosphere and the real eruption magnitude.

2) <u>Predicting the physics of magma unrest prior to a climactic eruption event</u>

In combination with igneous petrology as forensic enterprise to study past eruptions, volcanologists investigate the gas abundances preserved in pristine melt inclusions hosted in minerals from erupted volcanic rocks, which can reveal the gas cargo composition and amount and magma pressurisation at depth. In magma reservoirs at depth, gas bubbles form by exsolution or degassing of fluid components from the magmatic melt. Degassing and the competition between magma's capability to retain *or* release gas exert a major control on magma ascent and eruption. At low gas volumes, bubbles are sufficiently distant from one another to prevent their coalescence and magmas remain rather impermeable. A gas-rich magma is impermeable until bubbles begin to touch and at least one cluster of interconnected bubbles spans the entire volume and magma becomes permeable to gas flow. Magmas become permeable bodies when a certain gas volume or "percolation threshold" is reached. So far, there have not been clear constraints on how gas percolation threshold is controlled by chemical and physical parameters. Volcanologists as Earth-care professionals who record the warning signs that may presage the future eruption still struggle in the assessment of the true volume of gas stored in magmas, the true level of magma pressurisation, and the true volume of eruptible magma prior to the eruption event.

The lack of predictable linear correlations between volcanic parameters, such emitted gas and erupted magma, jeopardises the assessment of when and how large an eruption occurs at the specific monitored active volcano. This issue impedes to forecast the magma's propensity to release gas, which favours effusive activity, *and* its capability to retain it, which favours explosive eruptions. DE BELLO VULCANICO therefore underlines the urgent need of developing new strategies for decoding the volcanic precursors, forecasting volcanic eruptions, and developing novel risk assessment strategies to save lives and reduce damage property costs. Currently, major research initiatives aim to integrate satellite-based data into existing volcano monitoring platforms, such as MOUNTS (Monitoring Unrest from Space) that apply multisensor satellite-based imagery, ground-based seismic data, and artificial intelligence to assist global monitoring tasks, Deep Earth CArbon DEgassing (DECADE) of the Deep Carbon Observatory that deploy advanced real-time volcanic CO_2 monitoring devices on twenty of Earth's most actively degassing volcanoes, and Anticipating Volcanic Eruptions in Real Time (AVERT) that deploy an array of instruments on Cleveland and Okmok in the Aleutian Islands to improve forecasts of volcanic eruptions. As identified in the ERUPT (Volcanic Eruptions and Their Repose, Unrest, Precursors, and Timing) report, accurate forecasts of the likelihood and magnitude of an eruption in a specified timeframe are rooted in a scientific understanding of the processes that govern the storage, ascent, and eruption of magma. Therefore, it is a crucial mission for the 21st-century volcanologists to unravel the predictability of volcanic phenomena by synergising modern technology with observational, laboratory, and computational volcanology. Defeating the ignorance of the causes of volcanic eruptions is the way that we "were not made to live as brutes, but to follow virtue and knowledge" (Dante Alighieri, Divina Commedia 'Inferno', canto 26, l.118). The effort of *observo experior praedico* has to continue. *Ālea iacta est* ("The die has been cast").

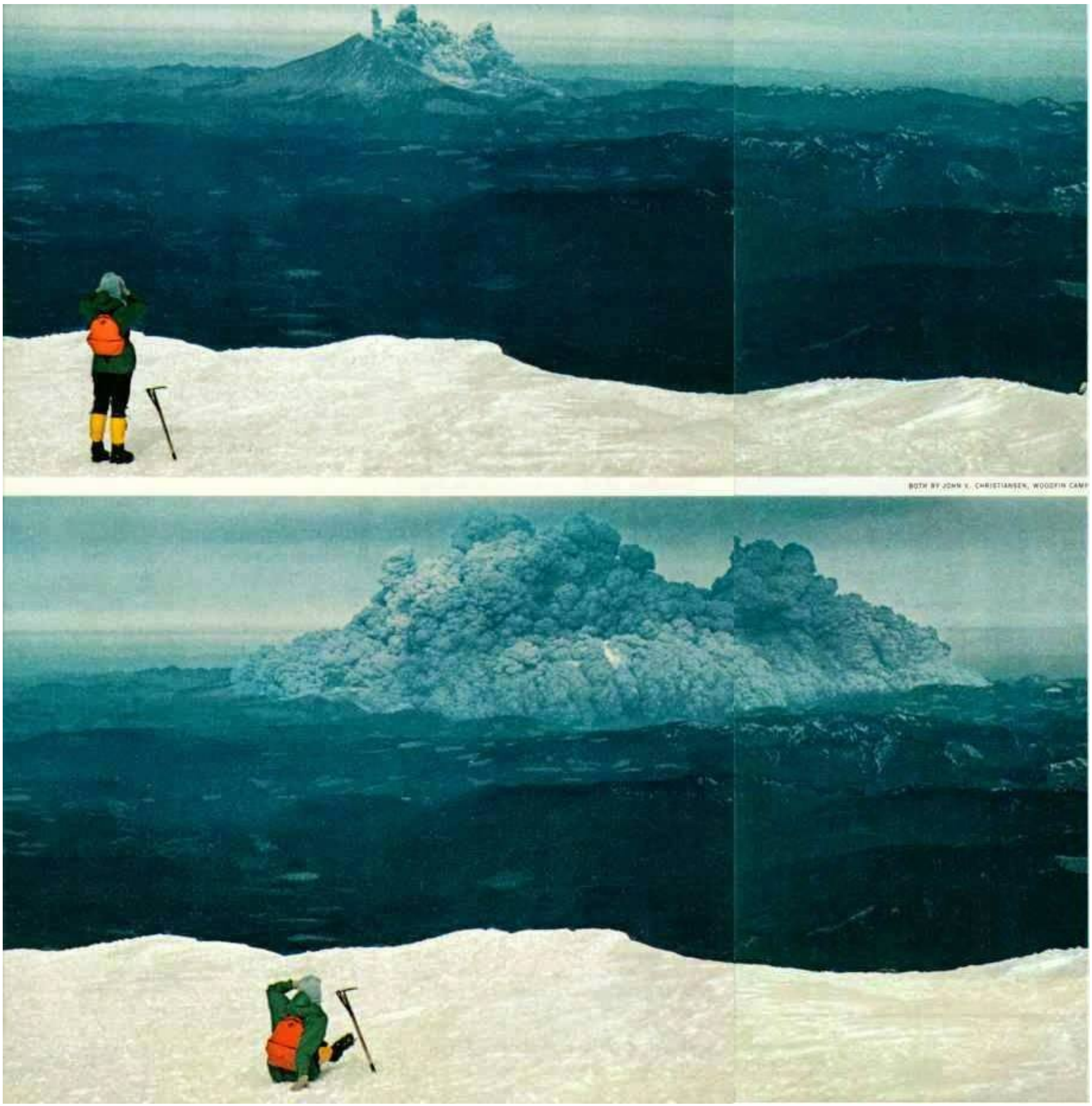

Figure 1: Eruption of Mt St Helens (WA, US) on May 18, 1980, with John V. Christiansen as spectator. Picture taken from Mt Adams (WA, US) by Vince Larson around 8:32 am local time on May 18, 1980 and published in a 1981 National Geographic Society magazine.