A novel approach to reconstruct the plinian and co-ignimbrite phases of large eruptions - Campanian Ignimbrite

Alejandro Marti (*)(1), Arnau Folch (1), Antonio Costa (2), and Samantha Engwell (3)
(1) CASE Department, Barcelona Supercomputing Center (BSC-CNS), Barcelona, Spain
(2) Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Bologna, Italy
(3) Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Pisa, Italy
(*) *Alejandro.Marti@bsc.es*

Abstract- *Reconstructing the volume and tephra dispersal from volcanic super-eruptions is necessary to assess the widespread impact of these massive events on climate, ecosystems and humans. Recent studies have demonstrated that volcanic ash transport and dispersion models are unrivaled in accurately constraining the volume of material ejected and provide further insight about the eruption dynamics during these gigantic events. However, the conventional simplified characterization of caldera-forming super-eruptions as a single-phase event can lead to inaccurate estimations of the eruption dynamics and its impacts. Here, we apply a novel computational inversion method to reconstruct, for the first time, the two phases of the largest eruption of the last 200 ky in Europe, the Campanian Ignimbrite (CI) super-eruption. Additionally, we discuss the eruption's contribution to the Middle to Upper Paleolithic transition by evaluating its environmental and climate implications.*

I. Introduction

Volcanic super-eruptions, typically associated with caldera-forming events, are often multiphase. The typical scenario begins with a Plinian column (Fig. 1a) which destabilizes to produce collapsing fountains that shed pyroclastic flows spreading laterally along the ground[1], eventually leading to secondary, co-ignimbritic plumes (Fig. 1b). Source conditions for co-ignimbrite plumes vary considerably from those of Plinian plumes, with much larger source radii and lower initial velocities. In eruptions where both phases have occurred, tephra deposits are typically bimodal. Such deposits are commonly separated into constituent phases based on their grainsize characteristics, with the coarse mode attributed to the Plinian phase, and the fine mode attributed to the co-ignimbrite phase[2]. In order to correctly evaluate the magnitude of each eruptive phase, it is critical to constrain their eruption dynamics and quantify their Eruption Source Parameters (ESPs) independently.

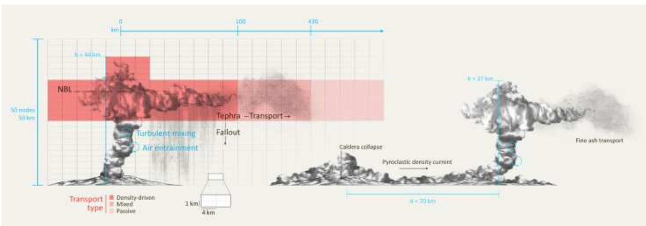

Figure 1. . Illustration of a typical multi-phase super-eruption with an initial (a) Sustained Plinian phase; followed by a (b) Caldera-collapse and large pyroclastic density currents eventually leading to secondary, co-ignimbritic plumes offset from the vent. Nodes with grey outline represent the model domain used for the CI model simulations. Our simulations used a grid spacing 0.2 degrees latitude and longitude (~4km), and 1 km cell height. Red nodes illustrate the effect of the density-current and the corresponding transport regimes in the umbrella cloud based on the best-fit model parameters (blue text) associated to the CI event.

Here, we apply a novel computational approach to reconstruct, for the first time, the two phases of the largest eruption of the last 200 ky in Europe, the Campanian Ignimbrite (CI) super-eruption[3] . It has been debated if the CI eruption, dated approximately 39.000 calendar years ago, was related to the disappearance of the remaining Neanderthals in Europe and, its interference with the territorial expansion of anatomically modern humans in the more southern parts of western Eurasia[4]. The event coincided with the onset of an extremely cold climatic phase (Heinrich Event 4) and the attendant episode of the Freno-Scandinavian ice cap and peripheral tundra on land. To conclude this work, we evaluate the environmental and climate-forcing implications associated to the eruption to provide new insights of the eruption's contribution to the Middle to Upper Paleolithic transition.

The aims of this conference paper are:

(1) To quantify the volume and tephra dispersal across Europe and Mediterranean area during each phase of the event.
(2) To describe the density-current effects in the umbrella cloud
(3) To discuss the eruption's contribution to the Middle to Upper Palaeolithic transition
(4) To provide an outreach interactive website for more information on this work (http://www.bsc.es/viz/campanian_ignimbrite)

II. Methodology

To reconstruct the tephra dispersal and the ESPs of the CI eruption, we used the FALL3D tephra dispersal model[5] in conjunction with a downhill simplex inversion method (DSM) to infer values of ESPs such as erupted mass, mass flow rate, plume height and total grain-size-distribution (TGSD). We compare the tephra dispersal and volume results from reconstructing the CI eruption as a two-phase event (Method 1), with those form the classical single-phase approach[6] (Method 2). Optimal inversion values for the ESPs were obtained by best-fitting two independent datasets containing tephra deposits separated into constituent phases. To account for the gravitational cloud spreading associated to the CI eruption, we couple FALL3D with a model that accounts for the density-driven transport in the umbrella cloud[7].

III. Results

A. Method 1: two-phase approach

Results for the best-fit model parameters for Method 1 suggest that the eruption began with a short, high-intensity ultra-Plinian explosive phase that yielded a column height of

44 km and a mass eruption rate (MER) of 3.75×10^9 kg/s. The Plinian phase lasted for 4 h, depositing a total of 54 km^3 (~22 km^3 DRE) of fallout material. After that time, the column would have collapsed to form radially spreading pyroclastic density currents, thereby superseding the Plinian column phase and leading to a co-ignimbrite phase. The co-ignimbrite column would have reached 37 km in height, fed by an average MER of 2.25×10^9 kg/s over 19 h, depositing ~154 km^3 (~62 km^3 DRE) of fallout material. Assuming that ~35-40% of the erupted material was elutriated from PDC[8] the total MER would have reached up to ~5-6×10^9 kg/s.

B. Method 2: single-phase approach

Best-fit simulation results from Method 2suggest a column height of 38 km, a mean MER of 2.55×10^9 kg/s and a duration of 23 hours. The amount of material deposited as tephra fallout totaled ~211 km^3 (~84 km^3 DRE).

C. Method 1 vs. Method 2

Method 1 is more accurate than the classical single-phase approach used in Method 2 (correlation coefficients 0.96 vs. 0.74) and in previous studies[6]. Both methods confirm the dominant role of the co-ignimbrite phase in the total bulk volume of the eruption. The amount of material deposited as fallout amongst experiments differed in less than 1.5%, a very consistent result. Method 1 simulated the dispersal of tephra (0.5 cm thick or larger) to be 15% smaller than Method 2, and 20% smaller than previous studies[6].

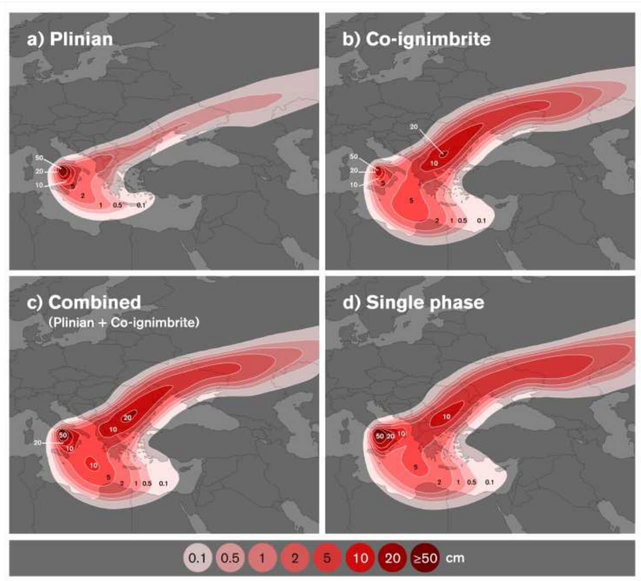

Figure 2. Model isopach maps showing the best-fit FALL3D tephra dispersal deposit (cm) for each phase of the CI super-eruption. Tephra dispersal is shown for (a) the 44km high ultra-plinian plume accumulating a total of 54 km^3 of fallout material; (b) the 38 km co-ignimbrite plume accounting for 74% of the total fallout material; (c) the combined Plinian and co-ignimbrite phases accumulating a total of 208 km^3 of fallout material over ~3 million km^2; (d) the classical single-phase approach for an eruption duration of 23h.

D. Density-current effects

We find the density-driven transport to be dominant for the first hour with an effective spreading radial velocity of ~130 m/s and producing an umbrella cloud radius of ~100 km. Model results show the effect of the density-driven transport to be significant in proximal areas, where tephra deposition is 1.5-2 times higher NE from the source and up to 50% lower in the east Mediterranean region due to the wind direction. These values are lower than expected for an eruption of such a magnitude. This is due to the strong stratospheric wind velocity of ~90 m/s found at the transport height above the vent.

IV. CONCLUSIONS

We bring to light valuable new results and methods in reconstructing the 39 ky CI super-eruption, accounting for both Plinian and co-ignimbrite phases. Simulation results show tephra fallout predominantly originated from the co-ignimbrite clouds. Density-current processes would have been significant in proximal areas. However, tephra transport would have been primarily dominated by wind advection, most likely as a result of intense stratospheric winds corresponding to best-fit synoptic conditions. Ecosystem recovery would have required tens to thousands of years depending on the thickness, nature and distance from source of the tephra deposits.

We suggest that the eruption would have cause a demographic crash among modern human populations boosted by the impact of the synchronous Heinrich Event 4 and the attendant episode of glacial advance on land. Such crash would have favoured the persistence of the Neanderthals in the Iberian Peninsula and not their disappearance as previously thought.

ACKNOWLEDGMENT

A.M. thanks the CASE visualization team at the BSC for their contribution to this work.

REFERENCES

1. Sparks, R. S. J., Wilson, L. & Hulme, G. Theoretical modeling of the generation, movement, and emplacement of pyroclastic flows by column collapse. J. Geophys. Res. Solid Earth 83, 1727–1739 (1978).

2. Engwell, S. L., Sparks, R. S. J. & Carey, S. Physical characteristics of tephra layers in the deep sea realm: the Campanian Ignimbrite eruption. Geol. Soc. London, Spec. Publ. 398, 47–64 (2014).

3. Fedele, F., Giaccio, B., Isala, R. & Orsi, G. The Campanian ignimbrite eruption, Heinrich event 4, and Palaeolithic change in Europe: a high-resolution investigation. In Volcanism and the Earth’s Atmosphere 139, 301–325 (American Geophysical Union, 2003).

4. Zilhão, J. Neandertals and moderns mixed, and it matters. Evol. Anthropol. 15, 183–195 (2006).

5. Costa, A., Macedonio, G. & Folch, A. A three-dimensional Eulerian model for transport and deposition of volcanic ashes. Earth Planet. Sci. Lett. 241, 634–647 (2006).

6. Costa, A. et al. Quantifying volcanic ash dispersal and impact of the Campanian Ignimbrite super-eruption. Geophys. Res. Lett. 39, L10310 (2012).

7. Costa, A., Folch, A. & Macedonio, G. Density-driven transport in the umbrella region of volcanic clouds : Implications for tephra dispersion models. Geophys. Res. Lett. 40, 4823–4827 (2013).

8. Sparks, R. S. J. & Walker, G. P. L. The significance of vitric-enriched air-fall ashes associated with crystal-enriched ignimbrites. J. Volcanol. Geotherm. Res. 2, 329–341 (1977).