Paleomagnetic behavior of very recent lava flows, the 2021 Cumbre Vieja eruption, La Palma, Spain

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1. Introduction

Volcanic rocks are used as a source to study the ancient behavior of the Earth's magnetic field. When volcanic rocks cool in the geomagnetic field, they archive the past direction and intensity. While obtaining paleodirections is relatively easy, obtaining information about the intensity of the Earth's magnetic field is much more difficult. Usually, only 10-20% of the samples used in classic paleointensity methods are successful.

In September 2021, the Cumbre Vieja volcano on the island of La Palma, Canary Islands, Spain, erupted. While this event brought massive destruction to the island it was also a unique chance to study the paleomagnetic behavior of very recent volcanics. Here, we study if the Earth's magnetic field is correctly stored in these young lava samples and how it varies for different parts of the flow. We focus on the intensity and will see whether this changes over time.

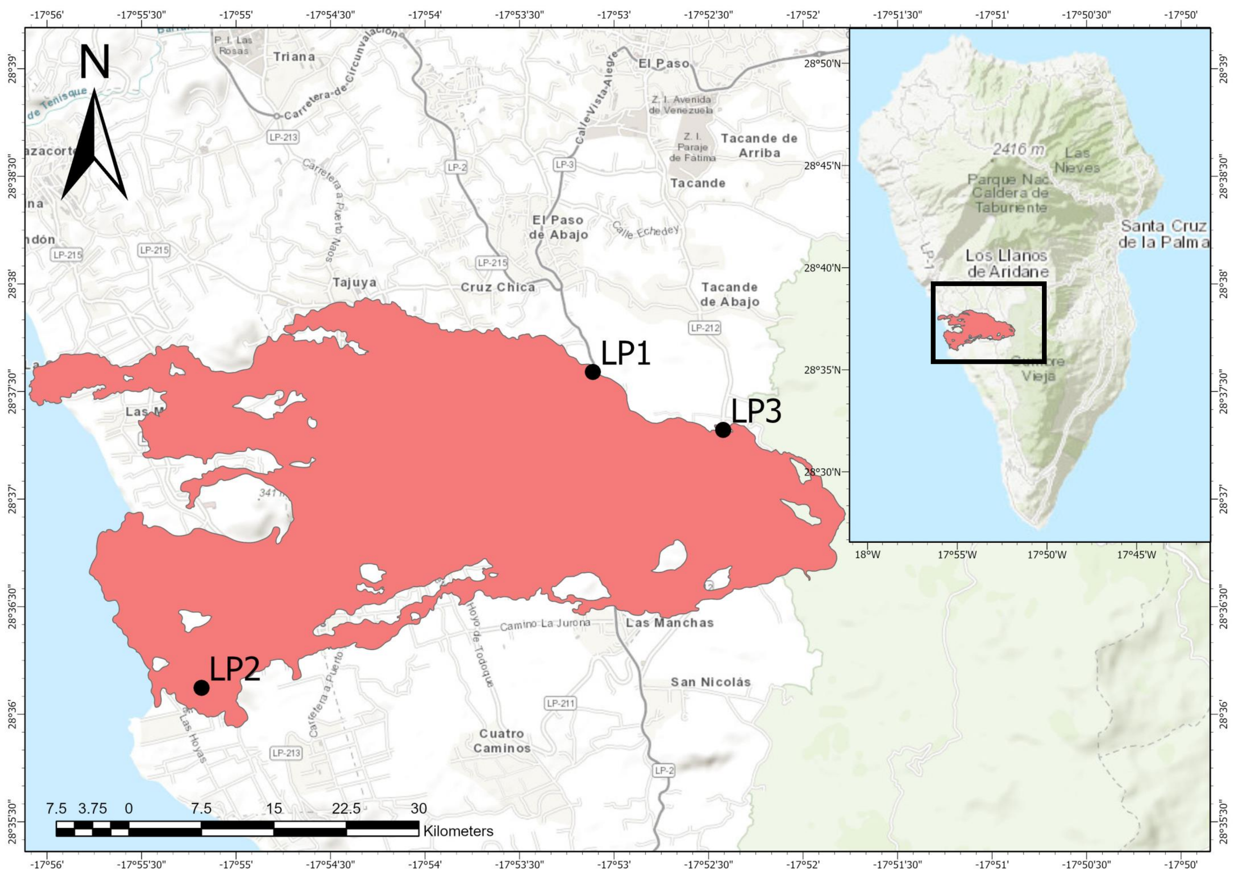


Figure 1: Map of the island of La Palma with in red the area covered by the 2021 flow. LP1, LP2, and LP3 are the locations of the sampling sites in this study

2. Geological setting and sampling

La Palma is one of the seven islands of the Canary Islands, Spain. At the southern tip of the island, the Cumbre Vieja volcanic ridge is located where since ~125ka volcanic activity has centered [1]. The eruption of 2021 lasted 85 days and was the largest eruption in the recorded history of the island [2]. The fieldwork was carried out in November 2021, when the volcano was still active. Therefore, the youngest part of the flow was less than 2 weeks old when sampled. At three sites, LP1, LP2, and LP3 (Figure 1), samples were taken around 0.5m apart from each other. Sampling was difficult along the Southern edge of the flow (Figure 2). Because of the predominant northwestern wind, a thick layer of ash was already deposited on top of the young flow which made finding a suitable sampling site troubling. Nonetheless, between 9-19 standard paleomagnetic cores of 5-10cm in length were drilled at each site (Figure 3) and samples were oriented with a magnetic compass. From sites LP1 and LP3 unoriented volcanic glass, which is rapidly cooled volcanic rock, was collected as well. Samples were transported back to Utrecht University in magnetically shielded boxes.

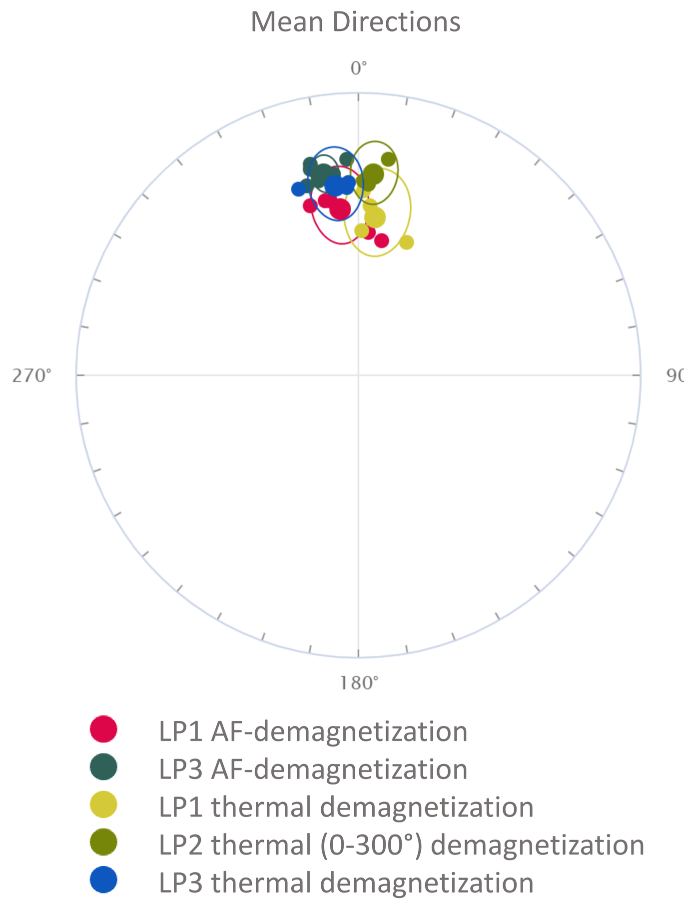
Figure 3: Paleomagnetic sampling performed at site LP1 with a water-cooled drill

Figure 2: Situation at the Southern edge of the flow, the new lava flow is covered with ash

3. Paleodirections

Paleomagnetic directions were obtained with both thermal and alternating field (AF)demagnetization experiments. Four samples per site were thermally demagnetized. Zijderveld diagrams indicate that LP2 has moved during cooling, only the low temperatures (0-300°C) cluster with LP1 and LP3 and are therefore interpreted. A further eight samples per site were demagnetized by increasing alternating fields on a robotized cryogenic magnetometer [3]. LP2 lost most of its magnetization at fields under 60mT and the results were too scattered to be reliably interpreted, it is therefore not used for calculating the mean directions.

Mean directions are shown in Figure 4. The expected direction on La Palma in October 2021 was -4.9° for declination and 37.1° for inclination. The results from our samples yields a +0.9° difference with the reference declination and -2.2° for inclination.



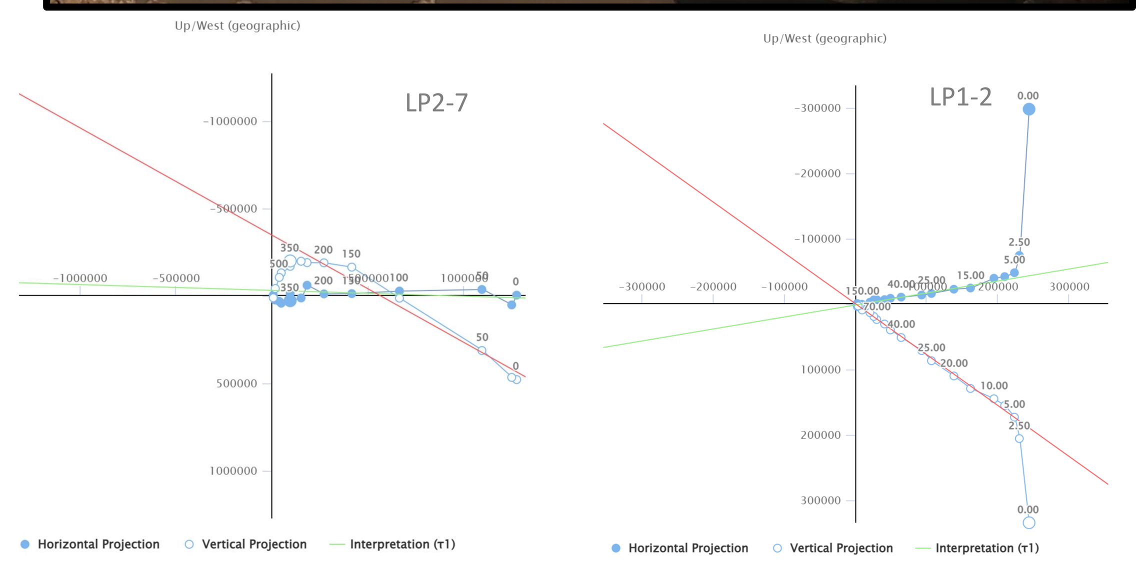


Figure 4: Directional results. Left) equal area projection of thermal demagnetization and AF demagnetization. Right) two example Zijderveld diagrams of LP2-7 (thermal) and LP1-2 (AF)

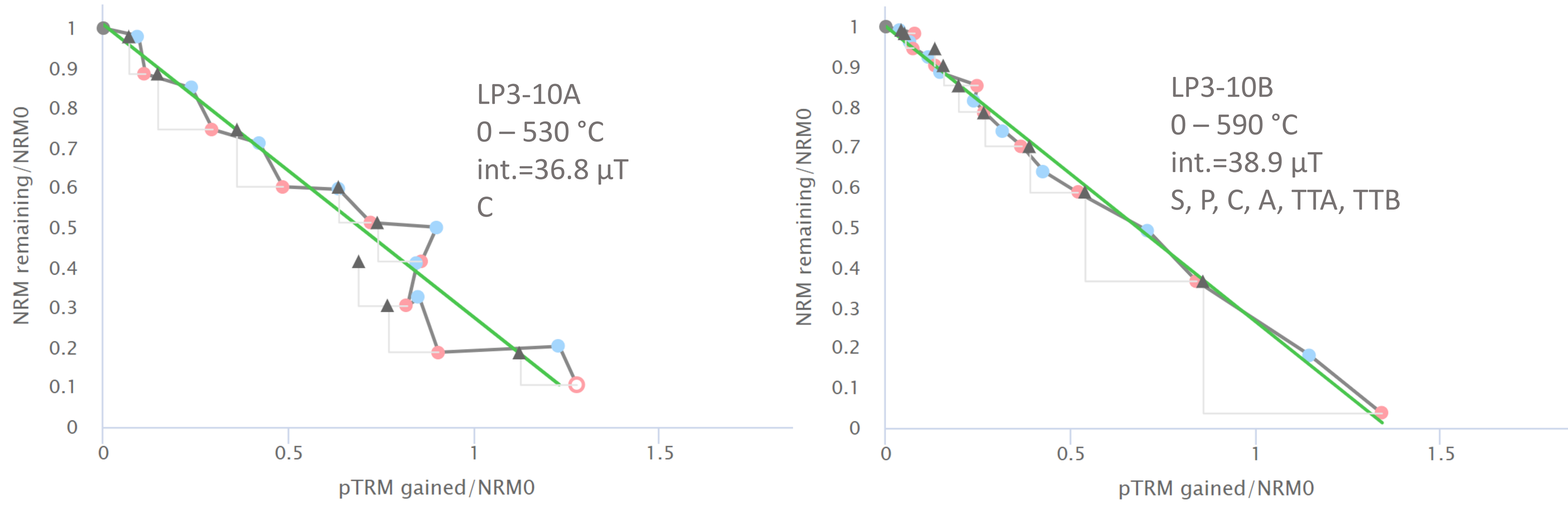


Figure 5: Paleointensity results of two samples from LP3. 10A is from the inside of the core, 10B from the outside. The green line is the largest interpreted segment. The six selection criteria are: S= SELCRIT, P=PICRIT, C=CLASS A, TTA, TTB. The expected intensity on La Palma in October 2021 was 38.7µT

4. Paleointensities

The paleointensity was derived from 72 samples using the IZZI-Thellier technique. With this method, samples are heated in several steps whereby the natural remanent magnetization (NRM) is progressively replaced by a partial thermal remanent magnetization (pTRM) under a laboratory field. Usually, samples for paleointensity experiments are prepared from the inside of cores to limit the amount of possible alteration. Here, for the IZZI-Thellier method we used samples from both the inside (A-samples) and outside (B-samples) of cores. For LP1 and LP3, five volcanic glass samples were included in the measurements.

The IZZI-Thellier method was very successful, 80% of the samples passed at least one of the six selection criteria. The least successful was LP2, because of the rotation. The results from LP1 and LP3 were very close to the reference field of 38.7µT. LP2 had the largest deviation of -6.8µT. On average the results remain very accurate, the average for all sites deviated only -0.15µT from the expected value. The samples from the inside (A) were less successful, 64% passed at least one selection criteria. There were 1358 number of interpretations, and the average deviation was -1.4 µT. Of the samples from the outside (B) 80% passed at least one selection criteria, with 2644 interpretations, and the difference with the reference field was only -0.1 µT.

5. Discussion and conclusion

The paleomagnetic data obtained from the La Palma 2021 flow agrees reasonably well with the expected IGRF-values. The declination is very close to the reference value, inclination is lower than expected. A 2-3° lower inclination is often reported for volcanic rocks [5].

This study was mostly aimed at the detailed paleointensity measurements. We found that these young volcanic rocks give exceptional results compared to regular paleointensity studies. The volcanic glass samples yielded the most accurate results, but also the outside of the paleomagnetic cores was more accurate than the inside. This might be attributed to a faster cooling rate. Faster cooling rates are thought to create smaller grain sizes and thus single-domain (SD) magnetic particles. SD particles behave ideally during paleointensity experiments, which would explain the excellent results of the volcanic glass and B-samples.

In this study, samples were not only taken around 0.5m apart from each other, they were also from different parts of the flow. This attributed to the accurate result of the average of the three sites. It shows that in case of sampling for paleosecular variation purposes it is preferred to, where possible, take samples spread out over a larger distance.

Outlook

For future research we prepared another 4 batches for the IZZI-Thellier method. Two of them are stored in the Earth's magnetic field, and two in a shielded environment. These samples will be measured in 2024 and 2025, to see whether results have changed over time and whether the presence or absence of a geomagnetic field influences their stored magnetizations. Additionally, we plan to visit La Palma again to re-visit our sites. Unfortunately, all our sampling sites seem to be covered by a new part of the flow. LP1 and LP3 might be still accessible, unfortunately we can not visit the exact location of LP2.

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