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Palaeointensity record through the Lower Mammoth reversal from the Waianae volcano, Hawaii

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Abstract

The normal to reverse Lower Mammoth reversal (3.33 Ma) has been recorded in several sequences of lava from the Waianae Volcano, the Island of Oahu, Hawaii. 137 samples from 29 flows from the Pu'u Paheehee section have been the subject of a palaeointensity study using the microwave technique. Duplicate sister samples from the directional study of Herrero-Bervera and Valet (Earth Planet. Sci. Lett. 171 (1999) 139–148) were used. Microwave demagnetisation was carried out on all samples and the directions compared to the published flow mean directions. Microwave palaeointensity experiments were carried out on all accepted samples using the 8.2 GHz and 14 GHz microwave systems. The perpendicular applied field palaeointensity method and a Coe analogue method were used. Eighty-four samples from 24 flows gave acceptable palaeointensity results. The results indicate that the geomagnetic field was low (mean 5.9 ± 1.3 μT (N=7)) prior to the transitional directions. During the first stage of the reversal the field remains low. Results however could only be obtained from three transitional flows. The field then strongly recovers with very high intensity (70 μT) and reversed direction. After this the intensity decreases before the field becomes transitional again for a cluster of four flows. The field does not reduce as much as previously, rather it is about twice the pre reversal intensity. For the final section of reversed flows the intensity is more than twice the pre reversal mean value, 15.1 ± 5.9 μT (N=7). Whilst some similarities are seen between this reversal and other reversals of different ages and locations there is not enough data at present to say whether there is any systematic behaviour.

Keywords: reversals; palaeointensity; microwave; Lower Mammoth; Hawaii

1. Introduction

The behaviour of the past geomagnetic field and its evolution in time set fundamental constraints in any model of the generation of the Earth's magnetic

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field in the liquid outer core. It is therefore essential for a better understanding of physical processes in the Earth's deep interior, particularly in the core and at the core–mantle boundary. One of the key features of the geomagnetic field is its ability to reverse polarity, with several hundred reversals having occurred over the last 160 Ma [1]. Reversals take a finite time but one that is very short on the geological time scale. Recent estimates suggest that the average duration is about 7000 yr but with the time depending on the latitude of the site [2]. It is essential to consider the full geomagnetic vector (directions and intensity) to fully understand the reversal process [3] with reliable records of the full geomagnetic vector during the reversal process providing important constraints for geodynamo models [4,5].

Reversal records can be found in both sedimentary and volcanic sequences. Whilst sedimentary sequences give a relatively continuous record of the field, the nature of the sediment recording process can lead to delayed remanence acquisition and smoothing of the magnetic record e.g. [6,7]. Volcanic rocks on the other hand record a 'snap shot' of the field and are not affected by smoothing but the inherent erratic nature of volcanic eruptions can lead to a sporadic recording of the geomagnetic field and a lack of temporal control e.g. [8]. The major advantage of volcanic sequences however, is that it is theoretically possible to obtain absolute (as opposed to relative for sediments) palaeointensity data as well as directional information. Areas of intense, widespread volcanism in which there are extensive, contiguous lava sequences are required. The lava sequences on the Islands of Hawaii are ideal. The Lower Mammoth reversal (3.33 Ma) as recorded on Oahu is one of the five most detailed directional records of a reversal from volcanic sequences [9]. It is therefore an ideal candidate for a palaeointensity study so that the full geomagnetic field behaviour can be determined to further our understanding of geomagnetic reversals.

To obtain reliable palaeointensity results, the natural remanent magnetisation (NRM) of the samples should be a thermal remanent magnetisation (TRM), the remanence carriers should behave as non-interacting single domain grains and there should be no thermo chemical alteration of the samples during the laboratory experiment. Alteration of samples due to laboratory heating is a common cause of experimental failure but by using the microwave palaeointensity technique, this alteration can be minimised. The microwave palaeointensity method is analogous to the usual Thellier method and its variants [10,11] where samples are successively heated and cooled in an oven to de(re)magnetise. Rather than using an oven for de(re)magnetising high frequency microwaves are instead used to directly excite the magnetic system so that the bulk of the sample remains at a much lower temperature [12–16]. This minimises sample alteration during the experiment and hence a greater experimental success rate is obtained e.g. [17–20].

2. Geological setting, age and sampling locality

The island of Oahu, Hawaii consists of two coalesced volcanoes. To the west is the Waianae volcano and to the east the younger Koolau volcano. The geology and evolution of the Waianae volcano has been well described ([21–26] and references therein). A schematic geological map is shown in Fig. 1. The volcano has been divided in to four members. The oldest Lualualei Member consists of the shield building lavas. The Kamaileunu Member consists of lavas from the later shield building stage. The post shield stage is the Palehua Member with the youngest Kolekole Member Volcanics uncomformably lying on top. The sequences of lava have recorded the Earth's magnetic field from 3.9–2.9 Ma (K–Ar dating), which encompasses the Gilbert Gauss reversal and the Mammoth and Kaena events. The Lower Mammoth reversal (3.33 Ma) is found within the Kamaileunu Member of the Waianae Volcanics (~3.5.1 Ma [26]) (Fig. 1). K–Ar dates have been obtained for the section at Pu'u Mailiilii [26] and confirm that the reversal is the Lower Mammoth. The bottom of the section gives an age of 3.35 ± 0.03 Ma, the middle 3.33 ± 0.04 Ma and the top an age of 3.22 ± 0.04 Ma. Three hundred metres away from Pu'u Mailiilii is the stratigraphically equivalent Pu'u Paheehee section [27]. Two other sections containing the Lower Mammoth reversal are Pu'u Kamaileunu [28] and Pu'u Keaau. Herrero-