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$^{40}Ar/^{39}Ar$ age of cryptochron C2r.2r-1 as recorded in a lava sequence within the Ko'olau volcano (Hawaii, USA)

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ABSTRACT

The $^{40}Ar/^{39}Ar$ method was used to refine the dating of a volcanic sequence drilled in the Ko'olau volcano which recorded a period of anomalously shallow inclinations. Previously, this sequence was dated using the unspiked K-Ar method at ≈ 2.1 Ma (Laj et al., 2000). This age was questioned by Ozawa et al. (2005) based on unspiked K-Ar ages of 2.40 and 2.41 Ma for two stratigraphically younger lava flows. Our new $^{40}Ar/^{39}Ar$ isochron results date this period of low inclination between 2.52 ± 0.10 and 2.40 ± 0.17 Ma. The combination of our two most reliable ages allows us to propose an age of 2.46 ± 0.13 Ma for the magnetic anomaly that we attribute to the cryptochon C2r.2r-1. This age agrees with previous estimates on the Halawa section of 2.46 ± 0.12 Ma (Singer, 2014) and the São Gonçalo profile of 2.46 ± 0.08 Ma (Holm et al., 2008; Knudsen et al., 2009). Our $^{40}Ar/^{39}Ar$ ages confirm the unspiked K-Ar dating results of Ozawa et al. (2005), which were corrected for the mass-fractionation effect. Along with published data, our new ages permit to bracket the Makapuu late-shield stage between 2.6 and 2.2 Ma.

1. Introduction

Through the 1960–70s, the K-Ar dating of Hawaiian volcanoes (McDougall and Tarling, 1963, 1964; Doell and Dalrymple, 1973) contributed significantly to establish and refine the geomagnetic polarity timescale. An exhaustive narrative of this period, which highlights the decisive advances in the understanding of the plate tectonics and of the earth magnetic field behaviour, was provided by McDougall (2013 and references therein). Such a background and potential encouraged scientists to pursue combined magnetic-dating studies, mainly because high extrusion rates volcanoes (e.g., Hawaii shileds, Garcia et al., 2017) offer a high potential to record short duration events such as Earth magnetic excursions and magnetic reversals. Indeed, the Matuyama Brunhes reversal (Coe et al., 2004; Singer et al., 2005) and the Cryptochron C2r.2r-1 (Herrero-Bervera et al., 2007) were magnetically characterized and dated on lavas sequences from Maui and Oahu. Laj et al. (2000) studied a volcanic sequence drilled in the Ko'olau volcano that recorded a period of anomalously shallow inclinations (i.e. a significant deviation from the dipole field direction) that was dated using the unspiked K-Ar method to ≈2.1 Ma. This age was questioned by Ozawa et al. (2005) as they obtained unspiked K-Ar ages of 2.40 and 2.41 Ma for two lava flows from the same core but stratigraphically younger than the ones dated in Laj et al. (2000). Therefore, this contribution aims at clarifying the timing of this period of magnetic anomaly.

K-Ar ages obtained from tholeiitic basalts may be biased by unresolved excess argon, argon loss, fractionated ^{40}Ar, as well as K loss or gain due to alteration, leading to over or underestimated results (Calvert and Lanphere, 2006; Guillou et al., 2017). Indeed, as employed in the Laj et al. (2000) study, the unspiked K-Ar method implicitly assumes that the dated samples evolved as closed system and had no excess or fractionated Ar. As the $^{40}Ar/^{39}Ar$ technique may resolve these perturbations, we re-dated the sequence drilled in the Ko'olau volcano using this method, to assess which age (i.e. 2.1 Ma or 2.4 Ma) is more reliable for the partially recorded magnetic excursion in the Wheeler Air Force core (WAFC).

This new investigation allowed the accurate dating of the magnetic anomaly recognized by Laj et al. (2000) and contributes to improve the calibration of geomagnetic timescale. These new ages also contribute to refine the timing of the late-shield stage.

2. Samples and methods

2.1. Samples

The island of Oahu (Hawaiian archipelago) was formed by two coalescent volcanoes, Wai'anae and Ko'olau (Fig. 1). Wai'anae volcano, the oldest, was active between 3.9 and 2.9 Ma (K-Ar ages from Doell

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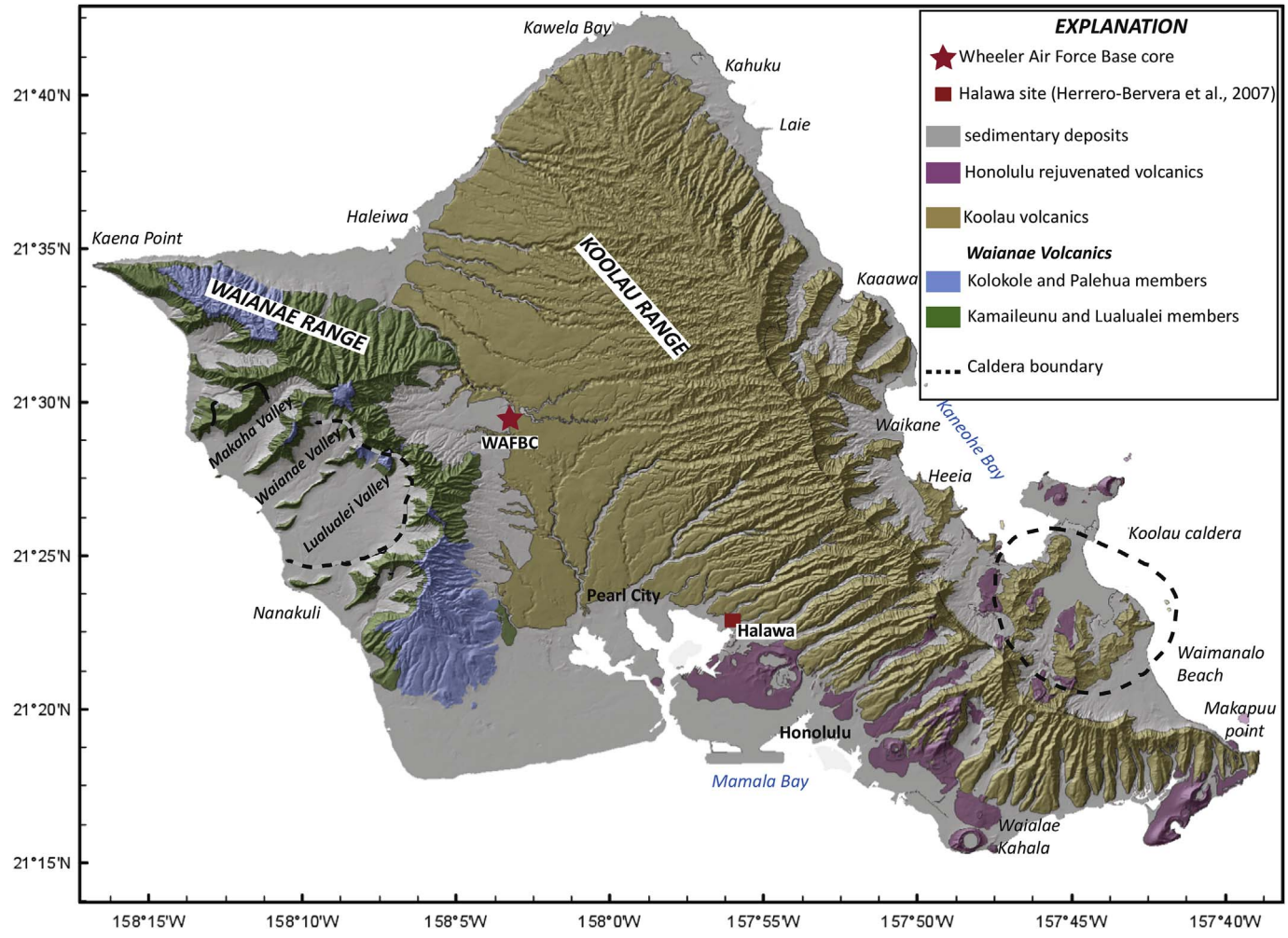

Fig. 1. Schematic geological map of Oahu modified from Sherrod et al. (2007), showing Wheeler Air Force core and Halawa site locations.

and Dalrymple, 1973; Presley et al., 1997; Guillou et al., 2000). Ko'olau has two rift zones extending northwest and southeast away from its caldera. A major collapse occurred along the Nuuanu landslide and destroyed more than the half of the eastern part of the volcano (Moore et al., 1994). When this landslide occurred is not exactly known but it is estimated to have occurred during the growth stage of the shield, between 2.2 Ma to at least 2.9 Ma (Garcia et al., 2006). Based on geochemical criteria, the shield stage is divided in two consecutive units (Shinozaki et al., 2002). The oldest one, the main shield stage, is only found as blocks within the Nuuanu landslide screes. One of these blocks, collected along the submarine flank of the volcano, was unspiked K-Ar dated to 3.31 ± 0.20 Ma (Yamasaki et al., 2011). The oldest subaerial lavas of the shield stage are $^{40}Ar/^{39}Ar$ dated to 2.8–2.9 Ma (Haskins and Garcia, 2004). The main shield stage is followed by the late-shield or Makapuu stage, which emptied small volumes of lavas (around 500–1000 km^3, Shinozaki et al., 2002) compared to the total volume of the Ko'olau (around 34 × 10^3 km^3; Robinson and Eakins, 2006). Unspiked K-Ar ages of Makapuu lavas range from 2.58 ± 0.13 to 2.10 ± 0.04 Ma (Laj et al., 2000; Ozawa et al., 2005; Yamasaki et al., 2011).

The WAFC contains a 200 m thick sequence of 29 Makapuu tholeiitic basalt lava flows. These lavas of reversed polarity emplaced during the first 0.5 Ma of the Matuyama chron (Laj et al., 2000). At depths ranging between approximately 130 m and 155 m, 2 lavas show a significant drop to shallower inclinations, which may coincide with a magnetic excursion (Fig. 2). For the latitude of this site, the expected inclination is around −38°, whereas the two anomalous flows have inclinations of about −16°. The three samples investigated here are from this portion of the core. They were collected from the most massive part of three slightly vesicular lavas at respective depths of −126.1m (OAU-07/KO19), −152.9m (OAU-09/KO21) and −162.9m (OAU-10/KO25). On the basis of two unspiked K-Ar ages, this anomalous zone was interpreted as a partial record of the Reunion event (Laj et al., 2000). This result was subsequently questioned by Ozawa et al. (2005).

2.2. The unspiked K-Ar technique

New splits of purified groundmass separates from samples OAU-07, OAU-10, which brackets the geomagnetic excursion (Fig. 2) and were already K-Ar dated by Laj et al. (2000), as well as splits of groundmass of sample OAU-09 were prepared following the procedure described by Guillou et al. (2000). The absence of alteration phases in the samples was verified by observations with a binocular microscope. These splits were used for both unspiked K-Ar and $^{40}Ar/^{39}Ar$ analyses and major element content determinations. Major elements were obtained using a Jobin & Yvon Horiba Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) of the Pôle de Spectrométrie Océan (PSO) at IUEM Plouzané, following analytical protocol of Cotten et al. (1995).

Isotopic compositions of Ar were determined via the unspiked method (Charbit et al., 1998) and achieved using a high-efficiency new argon extraction, purification and transfer line recently developed at the LSCE (Laboratoire des Sciences du Climat et de l'Environnement). Transfers of glass bulbs enclosing the argon samples after their