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Geomagnetic field secular variation in Pacific Ocean: A Bayesian reference curve based on Holocene Hawaiian lava flows

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ABSTRACT

Hawaii is an ideal place for reconstructing the past variations of the Earth's magnetic field in the Pacific Ocean thanks to the almost continuous volcanic activity during the last 10 000 yrs. We present here an updated compilation of palaeomagnetic data from historic and radiocarbon dated Hawaiian lava flows available for the last ten millennia. A total of 278 directional and 66 intensity reference data have been used for the calculation of the first full geomagnetic field reference secular variation (SV) curves for central Pacific covering the last ten millennia. The obtained SV curves are calculated following recent advances on curve building based on the Bayesian statistics and are well constrained for the last five millennia while for older periods their error envelopes are wide due to the scarce number of reference data. The new Bayesian SV curves show three clear intensity maxima during the last 3000 yrs that are accompanied by sharp directional changes. Such short-term variations of the geomagnetic field could be interpreted as archaeomagnetic jerks and could be an interesting feature of the geomagnetic field variation in the Pacific Ocean that should be further explored by new data.

1. Introduction

During the past few decades, great interest has been focused on the investigation of the past Secular Variation (SV) of the Earth's magnetic field in different parts of the world and several reference SV curves have been constructed at regional and global level mainly based on palaeomagnetic data from lava flows and archaeological artifacts. Such reference curves are particularly important as they are a unique source of information about the variations of the geomagnetic field in the past and the geodynamo processes at the mantle-core boundary. Based on the secular variation trend, particular interest has recently been concentrated on the identification of short-term variations in the direction and intensity of the Earth's magnetic field as evidenced in several parts of the world.

Investigating archaeomagnetic data from France, several periods characterized by rapid geomagnetic field changes were identified, known as archaeomagnetic jerks (AMJ). AMJ are defined as short periods (<100 yr) of sharp changes in the direction of the geomagnetic field accompanied by intensity maxima (Genevey and Gallet, 2002; Gallet et al., 2003; Valet et al., 2008). In Europe, several AMJs were identified in the last 8000 years (Gallet et al., 2003, 2005; Pavón-Carrasco et al., 2010; Tema and Kondopoulou, 2011), even though the origin of these jerks and their geographic appearance is still unclear (Dumberry and Finlay, 2007; Gallet et al., 2009). Gómez-Paccard et al. (2012) investigating the palaeointensity data from eastern and western Europe, observed two intensity maxima around 600 AD and 800 AD, and two abrupt geomagnetic field intensity changes during the 12th century AD and around the second half of the 13th century AD. de Groot et al. (2013) also indentified high intensity around 1000 AD in lava flows from Hawaii and compared it with other intensity maxima observed in Europe, Mesoamerica and Japan during the last 1500 years.

Hawaii is an ideal place for reconstructing the past variations of the Earth's magnetic field in the Pacific Ocean and for investigating in detail possible sharp regional variations and short-term behavior of the geomagnetic field in centennial scale. That's mainly because: 1) the archipelago of Hawaii is characterized by important volcanic activity with several lava flows erupted almost continuously during the last millennia; 2) a rich compilation of ^{14}C ages is available for a large number of lava flows thanks to the Hawaiian radiocarbon program; and 3) it is situated at the center of the Pacific Ocean offering a unique source of palaeomagnetic data for a large area that otherwise would be completely uncovered by geomagnetic field records. Thanks to these particular characteristics, the

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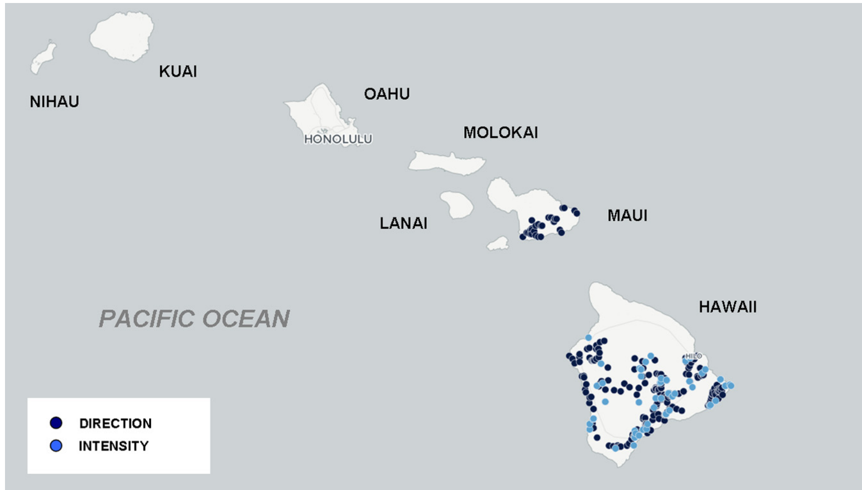

Fig. 1. Map of the Hawaiian Islands situated in the Pacific Ocean. All the available palaeomagnetic data from Holocene come from the Big Island of Hawaii and Maui Island.

Hawaiian lava flows have been thoroughly studied for the determination of both direction and intensity of the Earth's magnetic field in the central Pacific Ocean and for the investigation of a possible non dipole low secular variation in the Pacific (Coe et al., 1978; McWilliams et al., 1982; Tanaka and Kono, 1991; Mankinen and Champion, 1993; Herrero-Bervera and Valet, 2007).

Early studies of the historical secular variation rates in the Pacific region suggested that the non-dipole field change rate was anomalously low (Doell and Cox, 1963) and since then a considerable amount of research and discussion has been focused on the existence and duration of such low geomagnetic secular variation. Doell and Cox (1972) supported the hypothesis of a persistent Pacific low non dipole by studying Hawaiian lava flows. Such hypothesis was further sustained by new radiocarbon dated Hawaiian lava flows (McWilliams et al., 1982) and from lake sediment records from the Big Island of Hawaii over the past 10 000 years (Peng and King, 1992). On the other hand, several studies do not confirm such long-standing low non-dipole SV pointing the attention on the reliability of the reference data and problems related to fast eruption time intervals and sampling procedures (e.g. Coe et al., 1978; McElhinny et al., 1996).

Concentrating on the last millennia, Holcomb et al. (1986) proposed a reference SV curve for the last 3000 years, based on 67 radiocarbon dated Hawaiian lava flows and used it for dating recent Hawaiian lava flows of unknown age. Hagstrum and Champion (1995) calculated a SV curve for the last 4400 years based on 191 sites of historical and ^{14}C dated lava flows from Mauna Loa, Kilauea and Hualalai Volcanoes on the island of Hawaii, using the time window averaging technique. More recently, new reliable directional and intensity palaeointensity data from Holocene Hawaiian lava flows have been produced by several authors (e.g. Valet et al., 1998; Pressling et al., 2006, 2007, 2009; Sherrod et al., 2006; Herrero-Bervera and Valet, 2007; de Groot et al., 2013) also including palaeomagnetic data from long drill basaltic cores (e.g. Laj et al., 2002; Teanby et al., 2002; Gratton et al., 2005).

In this study, we have collected all updated directional and intensity data from Hawaiian historical and radiocarbon dated lava flows available for the last ten millennia in order to reconstruct the most detailed and well constrained SV path of both direction and intensity in the central Pacific during Holocene. All available radiocarbon ages were calibrated using the OxCal 4.2 program and the reference dataset was used for curve building. The most recent advances on curve building based on the Bayesian statistics were used for the calculation of smooth and continuous SV curves. The obtained curves are compared with global geomagnetic field models predictions and are used for the better understanding of the SV path in the central Pacific and the identification of possible sharp and rapid variations of the Earth's magnetic field in this area.

2. The reference dataset

The compilation of the Hawaiian lava flow data for the last 10 000 yrs was carried out by using single palaeomagnetic records recovered from the original publications. The direct use of global datasets was avoided in order to eliminate errors related to the gathering of huge amounts of data while the direct control of the original data makes also possible a better evaluation of individual data's reliability (Tema and Kondopoulou, 2011). In this study, palaeomagnetic data from long drill cores of projects such as the Hawaiian Scientific Drilling Project (HSDP) and the Scientific Observation Holes (SOH) were not included because, even if they offer a continuous and detailed record, they often lack precise dating. Indeed, dating of horizons within the cores is poorly constrained as it is usually based on linear interpolation among few radiometrically dated tie-points (Pressling et al., 2006).

The initially compiled Hawaiian dataset consists of 403 data: 322 directional records and 81 intensity records coming from 15 publications. Most of the data came from the Big Island of Hawaii, while some directional data also came from the East Maui volcano (Fig. 1). To guarantee the quality of the reference data, several selection criteria based on the number of samples studied and the quality of the direction and intensity determinations as expressed by the α_{95} angle and the standard deviation, were applied at the initial dataset. In the literature, various quality criteria are proposed by different authors in order to evaluate the quality and select the most reliable reference data for geomagnetic field reconstructions. However, the appropriate use of such quality criteria is still under discussion: the use of very strict criteria would lead to the elimination of a large number of data probably compromising the robustness of the calculated secular variation path while on the other hand the application of less strict criteria may allow the use of unreliable records and result to a smoother and less reliable secular variation curve. In this study, we decided to apply some selection criteria in order to eliminate data that were technically bad determinations but at the same time we tried not to loose too much information of the past geomagnetic field. We have therefore rejected all directional and intensity data that came from less than three independent sample determinations and all data that are characterized by $\alpha_{95} > 5°$ and $\sigma > 5$ μT. Data with missing information on the number of samples and/or α_{95} and k precision parameters were also rejected. After this selection, the final data set consists of 278 directional and 66 intensity data, covering the last 10 000 yrs. The distribution of the α_{95} and σ_F of