Physics of the Earth and Planetary Interiors 279 (2018) 79–91

Contents lists available at ScienceDirect

Physics of the Earth and Planetary Interiors

journal homepage: www.elsevier.com/locate/pepi

Last three millennia Earth's Magnetic field strength in Mesoamerica and southern United States: Implications in geomagnetism and archaeology

Avto Goguitchaichvili[a], Rafael García Ruiz[a,*], F. Javier Pavón-Carrasco[b,c], Juan Julio Morales Contreras[a], Ana María Soler Arechalde[a], Jaime Urrutia-Fucugauchi[a]

[a] Servicio Arqueomagnético Nacional, Instituto de Geofísica-Unidad Michoacán, Universidad Nacional Autónoma de México, Campus Morelia, Morelia Michoacán, Antigua Carretera a Pátzcuaro 8701, 57089, Mexico

[b] Dpto. de Física de la Tierra y Astrofísica, Facultad de C.C. Físicas, Universidad Complutense de Madrid, 28040 Madrid, Spain

[c] Instituto de Geociencias, CSIC – UCM, 28040 Madrid, Spain

ARTICLE INFO

Keywords:
Archaeomagnetism
Paleomagnetism
Paleosecular variation curve
North America
Paleomagnetic reconstructions
Holocene
Eastward drift

ABSTRACT

Earth's Magnetic Field variation strength may provide crucial information to understand the geodynamo mechanism and elucidate the conditions on the physics of the Earth's deep interiors. Aimed to reveal the fine characteristics of the geomagnetic field during the last three millennia in Mesoamerica, we analyzed the available absolute geomagnetic intensities associated to absolute radiometric dating as well some ages provided by historical documents. This analysis is achieved using thermoremanent magnetization carried by volcanic lava flows and burned archaeological artefacts. A total of 106 selected intensities from Mesoamerica and other 100 from the southern part of the United States represent the main core of the dataset to construct the variation curve using both combined bootstrap method and temporal penalized B-spline methods. The obtained intensity paleosecular variation curve for Mesoamerica generally disagrees with the values predicted by the global geomagnetic field models. There is rather firm evidence of eastward drift when compared to similar reference curves in Western Europe, Asia and Pacific Ocean. The recent hypothesis about the relationship between the geomagnetic field strength and paleoclimate is also critically analyzed in the light of this new data compilation.

1. Introduction

Revealing the fine-scale variations of the Earth's Magnetic Field (EMF) is one of the major objectives of all geomagnetic studies (Carrancho et al., 2017). These investigations may largely contribute to solve some critical issues about the origin and causes of the fluctuations of the geomagnetic field from the reversals and excursions to the jerks. Current observations of the geomagnetic field indicate that the dipolar contribution (about 90% of total field) is decreasing by about 10% since the eighteenth century (Genevey et al., 2009). On other hand, there is a general agreement among paleomagnetic community that during a geomagnetic reversal (or excursion) the absolute intensity may decrease up to 50% or even more (Laj and Channell, 2007) of its pre-transitional value. Korte and Constable (2008) speculated that this behavior may indicates a possible next large departure of the field. However, it is difficult to predict how these changes affects our planet (Jackson et al., 2015). Thus, it is crucial to reconstruct the past evolution of EMF elements. Another important question debated during the last decade is the possible influence of EMF variations on Earth's climate and biosphere. This still controversial hypothesis has gained a great interest during the last decade (Courtillot et al., 2007; Dergachev et al., 2013; Gallet et al., 2005, 2006).

Absolute geomagnetic intensity is a decisive element for a better knowledge of the geomagnetic field morphology. However, reliable absolute paleointensity values are generally much more difficult to obtain than directional data, because only objects carrying full thermoremanent magnetization and which satisfy some specific magnetic criteria may be used for paleointensity determination (Kosterov and Prévot, 1998). On other hand, the paleointensity determination has a great advantage because no *in situ* structures and thus oriented samples are required. Well constrained intensity paleosecular variation curves (PSVCs) already exist in Europe (Genevey et al., 2016, Gómez-Paccard et al., 2016, Hervé et al., 2013; Tema and Kondopoulou, 2011), Asia (Cai et al., 2016), and Tema et al. (2017), recently developed a PSVC for the Pacific Ocean based on Holocene lava flows from Hawaii. Unfortunately the number of archaeointensity data is low for the last 10,000 years which does not allow to reveal the fine characteristics of the EMF. However, in Americas, no such PSVC is available in spite of

* Corresponding author.
E-mail address: avto@geofisica.unam.mx (R.G. Ruiz).

https://doi.org/10.1016/j.pepi.2018.04.003
Received 7 September 2017; Received in revised form 20 February 2018; Accepted 7 April 2018
Available online 10 April 2018
0031-9201/

the great cultural heritage.

The first archaeomagnetic survey in Mesoamerica was carried out in Cuicuilco, near to Mexico City by Nagata et al. (1965). Coe (1967a) developed a study in San Lorenzo (Veracruz) and three years later Bucha et al. (1970) performed archaeointensity determinations on several pre-Columbian pottery samples from different archaeological sites of central and southern Mexico. A first chronology study of the past EMF based on Mesoamerican archeodirections was provided by Wolfman (1990) which complemented previous indirect directional data, coming from magnetically oriented buildings (first millennium BC) in Oaxaca and Tabasco (Urrutia et al., 1981, 1986). Almost two decades elapsed from these pioneering studies until late 90's, when numerous high quality determinations become available, provides new information of the EMF past evolution coming from both lava flows and previously archaeological sites (Alva-Valdivia, 2005; Böhnel et al., 1997; Goguitchaichvili et al., 2005; Hueda and Soler, 2000; Morales et al., 2001, 2006).

The present study pretends to construct an intensity PSVC for Mesoamerica during the last three millennia analyzing available and independently dated absolute geomagnetic intensities determined from volcanic lava flows and burned archaeological artifacts. This first reference PSVC may be used as preferred dating tool for the region.

2. Data and methods

The archaeomagnetic and paleomagnetic (lava flows) data used in the present study are distributed in the area which covers Mexico, Guatemala and the Salvador (Fig. 1). Most of the archaeointensities are available in the last version of GEOMAGIA50.v3 (Brown et al., 2015) and ArcheoInt (Genevey et al., 2008) while some volcanic data may be found in the most recent publications (Böhnel et al., 2016; García-Quintana et al., 2016). Remained archaeointensity determinations comes from published papers since early eighties. Mesoamerican data consist of 106 intensities (Appendix 1) and cover approximately the last 3000 years.

The archaeointensities were relocated to a common location (Mexico City) in order to avoid spatial dependences and to provide a continuous temporal information of the EMF in the selected region. The relocation procedure is achieved assuming a geocentric axial dipole field (Lanos, 2004; Casas and Incoronato, 2007), where the relocated intensities F_R, are calculated by the virtual axial dipole model (VADM) expression (Barton et al., 1979):

$$F_R = F_S\sqrt{(1 + 3\cos^2\theta_R)/(1 + 3\cos^2\theta_S)},$$

where F_s is the *in situ* intensity, θ_S is the site geographical colatitude, and θ_R is the colatitude of the reference point that was considered the

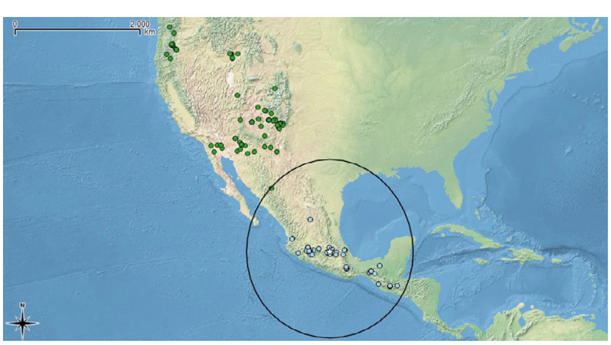

Fig. 1. a) Schematic map of location of samples analyzed in this study. The blue color refers to the samples belonging to Mesoamerica, with a circular area with radios of 1200 km, while intensities from southern United States are denoted in green. The map of this figure was produced with QGUIS 2.87 software (www.qgis.org). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

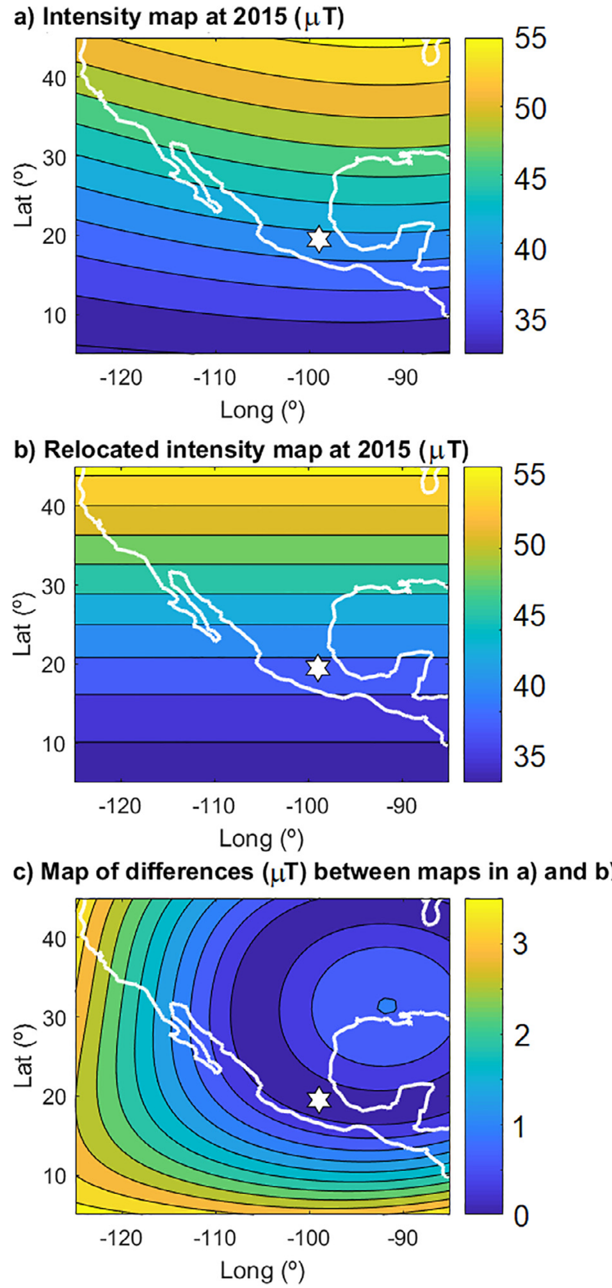

Fig. 2. Analysis of the relocation error. a) Intensity map for Mesoamerica and North America using IGRF-12 model at 2015.0 (Thébault et al. 2015). b) Map of relocated intensities to the coordinates of México City using the map in a). c) Map of absolute differences of both maps in a) and b) showing the relocated error (the bar of error is in microT).

downtown of Mexico City as the reference location (Lat. 19° 25.17′N, Long. 99° 8.73′W). All sites within the radius of less than ~1200 km from Mexico City were considered. The intensity data relocation introduces an error due to the non-dipole harmonic contributions of the EMF (Barton et al., 1979; Daly and Le Goff, 1996), which increases with the distance from the reference location. This error, called relocation error, was studied by Casas and Incoronato (2007) for different spatial and temporal coverage. We have performed here a similar analysis using synthetic intensity data from the IGRF-12 model at 2015.0 (Thébault et al., 2015), covering our interest area, i.e. a circular area centered in Mexico City with 1200 km (Fig. 1) of radius. The maximum relocation error was less than 0.5 μT, value lower than the mean intensity uncertainty of our selected database, i.e. ~ 4 μT (see Fig. 2).