ROADMAP TO BUILDING ECUADOR'S ARCHEOMAGNETIC RECORD – EXPERIENCES FROM THE FIRST NEW ZEALAND RECORD

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ABSTRACT

The reliability of the global and local models of the past Earth's magnetic field behavior relies on the quality, quantity and geographical extent of the input data. One of the high-quality inputs are the magnetizations carried by archeological artefacts. Fired archeological artefacts like baked clays, ceramics, soil, and kilns can record information of Earth's magnetic field the last time they were heated. Ecuador has a long and rich archeological history, but only very few archeomagnetic studies have been conducted so far. Here we present the roadmap to building the archeomagnetic record of Ecuador. As a guideline, we show how we proceeded in doing this in New Zealand during the past five years. The process consists of constructing the master paleomagnetic secular variation curve and compiling the archeomagnetic record. Improving the archeomagnetic record is a never ending process, since the resolution can only be improved by measuring more archeological artefacts. So far, 19 archeological sites around New Zealand have been studied, recovering reliable directional data from twelve sites and intensities from thirteen. The systematic studies in New Zealand have provided important data for regional and global geomagnetic field models, and, as well, have equipped local archaeologists with a new dating tool. In Ecuador, our next steps are to a) drill a long continuous lake sedimentary core in order to build the master curve and b) collect a representative set of archeological artefacts with good temporal and geographical extent.

Key words: Archeomagnetism, archeomagnetic dating, paleosecular variation, geomagnetic field models.

1. Introduction

In order to understand the behavior of the Earth's magnetic field in the past and to construct reliable global and local models we need high quality data from all around the Earth. Archeomagnetism can be useful for both a) providing invaluable information of the direction and strength of the magnetic field in the past, and b) obtaining an alternative or complimentary age estimate for materials that are not amenable to more traditional methods such as radiocarbon dating (Arneitz *et al*., 2017; *e.g*., Gallet *et al.*, 2009; Lanos and Philippe, 2015; Pavón-Carrasco *et al*., 2011; Stillinger *et al.*, 2016). Any material with small proportions of ferrimagnetic minerals become magnetized during the final cooling process from high temperatures. If an artefact or soil remains in situ until sampled, then the direction of its magnetization can provide a record of the direction of the surrounding magnetic field at the time of firing, and the strength of the magnetization gives a measure of the field intensity.

Over the past five years systematic archeomagnetic studies in New Zealand have provided important data for regional and global geomagnetic field models. In addition, local archaeologists have been introduced to a new, alternative dating tool, independent of or complimentary to 14C. Here we review the results of archeomagnetic research in New Zealand to date. This five years old, but continuing project in New Zealand will then be used as a roadmap for building a similar high resolution archeomagnetic record in Ecuador.

2. Methods and results

The first full Holocene (11,500 year-long) New Zealand master paleomagnetic secular variation record (NZPSV10k) was collected from the sediments of Mavora Lake (Turner *et al*., 2015). The record comprised of a composite of declination, inclination and relative paleointensity logs and an age model with 28 accelerator mass spectrometry radiocarbon (14C) age determination on short lived species.

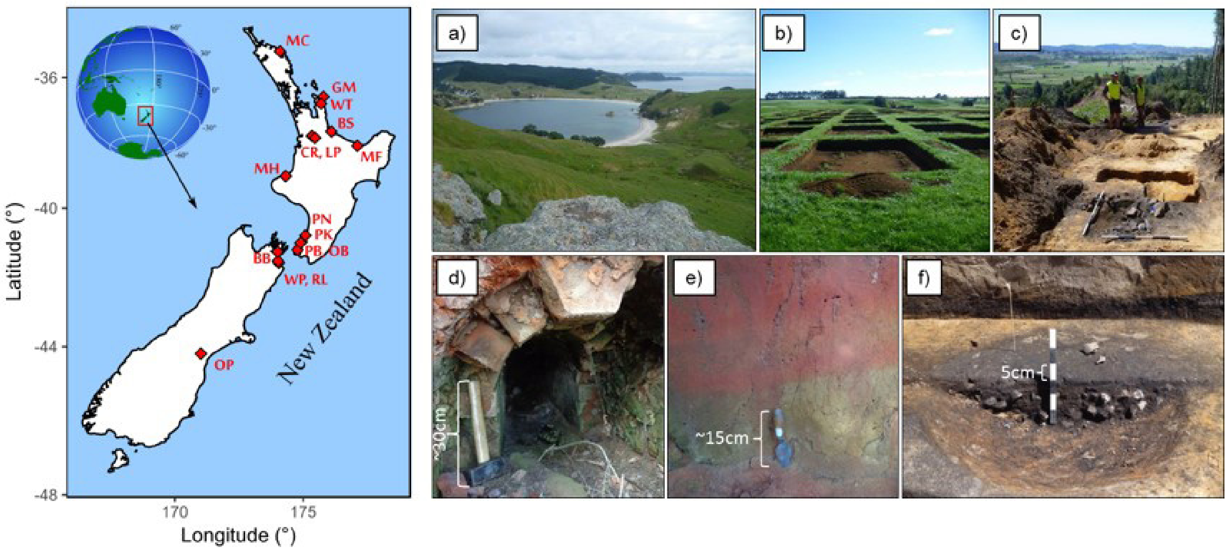

Figure 1. Archaeomagnetic sampling sites in New Zealand with couple of examples: a) Great Mercury Island, North Island (GM1-4), b) Mangahau, Taranaki, North Island (MH), c) Mataki Forest, Bay of Plenty, North Island (MF), d) A flue of an 1886 AD brick kiln at Pukerua Bay (PB), e) Baked soil that acted as a natural wall to the Pukerua Bay brick kiln (PB) and f) Half-excavated hangi (earth oven) at Cambridge Road, Hamilton (CR1)

In addition to the master curve, we have studied 19 archaeological sites around New Zealand (Fig.1). The primary target material has been stones from Maori hangi, which is a traditional New Zealand Maori method of cooking food using heated rocks buried in a pit oven. Recently we extended our methodology to bricks from brick kilns and various heat affected soils, such as those under fire pits. Radiocarbon (^{14}C) dating of charcoal fragments of short-lived species, found amongst the stones at some sites, indicates an age range from 1400 AD to the present-day. However, the calibration of the conventional ^{14}C ages to calendar years sometimes produces ambiguities. From the 19 sites studied we have been able to recover reliable directional data from twelve sites and intensities from thirteen. The main carrier of the magnetization is typically low titanium Ti-magnetite in the single domain to pseudo-single domain state, based on the rock magnetic analysis. Thellier paleointensity determinations on hangi stones yield intensities ranging from 55 to 76 μT. Our selection criteria for the paleointensities follows the classes TTA and TTB as outlined by Leonhardt *et al*. (2004) and further modified by Paterson *et al*. (2014).

The NZPSV10k master curve was tested for archeomagnetic dating by comparing the directional data from the archeological sites with the NZPSV10k master curve. In some cases, it helped to resolve the ambiguities arisen in the calibration of radiocarbon dates (Fig. 2), and in others provided the only available age control.

3. Discussion

The first New Zealand archeointensity record (Fig. 3) together with data from Australia and Southwest Pacific islands (Fig. 4; Barbetti, 1983; Stark, 2011), is consistent with predictions of the gufm1 global model (Jackson *et al*., 2000) back to 1838 AD, and its extension to 1590 AD. Prior to this date however, the data

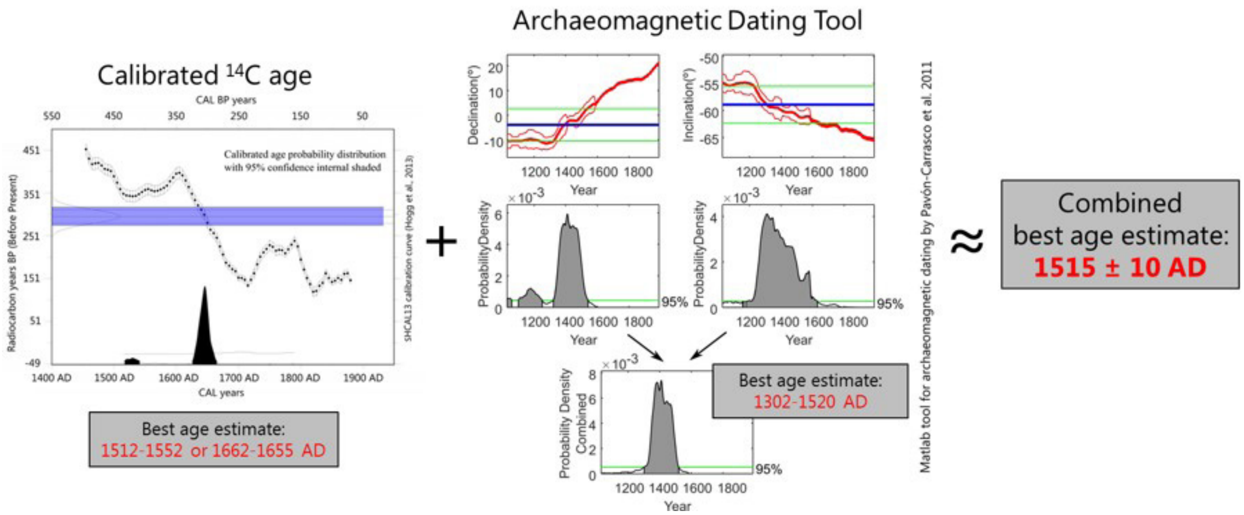

Figure 2. Example of the use of archeomagnetic dates to solve ambiguities of age. Hangi from Paekakariki (PK), which has a conventional ^{14}C age: 308 ± 15 BP and a paleomagnetic direction: D= -3.9°, I = -58.9°, α95 = 3.4° (after relocation to 40° S, 175° E). Archeomagnetic dating tool by Pavón-Carrasco *et al*. (2011) was used in the archeomagnetic dating.

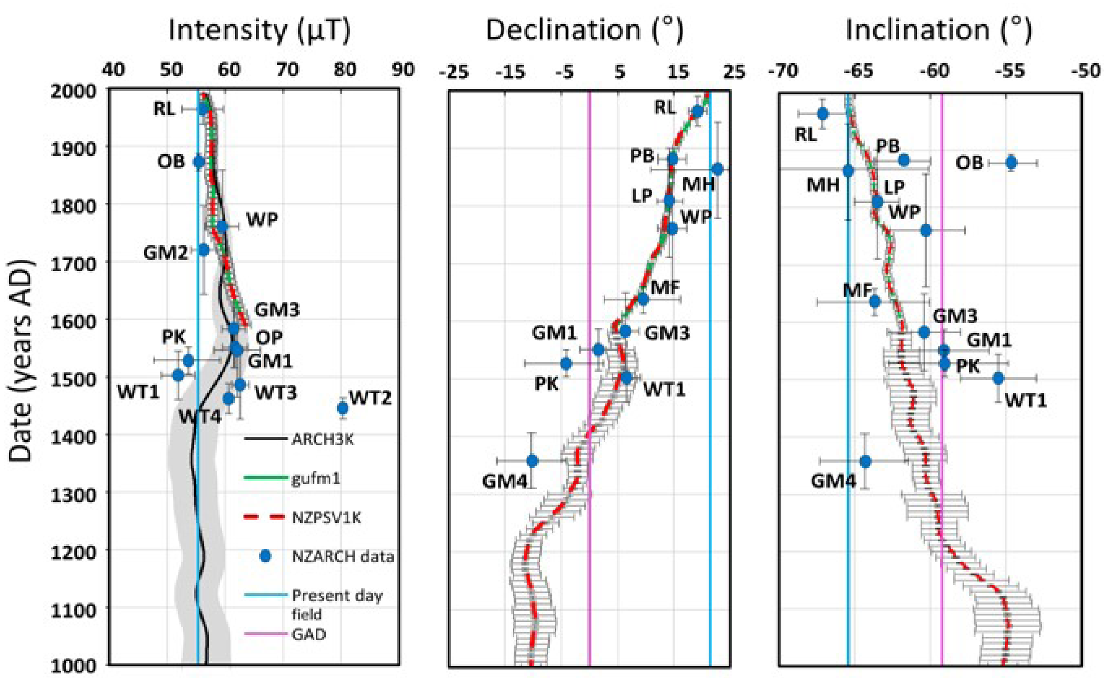

Figure 3.New Zealand's first archeomagnetic data (blue circles with their associated error bars), red curve with 95% confidence bars is NZPSV1K (Turner *et al*., 2015), black curve with grey cloud is ARCH3K (Korte *et al*., 2009) and green curve beneath the red curve is gufm1 (Jackson *et al*., 2000). All data and curves are relocated to 40° S 175° E.

suggests more rapid variations and some unusually high paleointensities. Comparison to archeomagnetic intensity records from South America and Europe reveals similar broad decreasing trend in the magnetic field strength the past four to five centuries, but also some differences, most strikingly the dominance of lower field values between 1000 to 1300 AD in Southern hemisphere data. More data from this time period is crucially needed both in general from Southern hemisphere as well as equatorial South America. This clearly highlights the necessity to build a high resolution archeomagnetic record from Ecuador. For example, we still do not know what are the dynamics of deep Earth processes such as the influence of core-mantle boundary interactions on geomagnetic variations including secular changes, excursions and polarity reversals (*e.g*. Gómez-Paccard *et al*., 2016; Livermore *et al*., 2014)? Furthermore for example equatorial flux spots (Jackson, 2003) or the South Atlantic Magnetic Anomaly (Hulot *et al*., 2002) are visible in the satellite data but not in archeomagnetic data. We have not been able to assess their stability or potential cyclicity due to lack of data. In order to help address these questions we have planned to drill an initial ~20 – 30 meter drill core out of lake sediments in Ecuador, construct the first ever Ecuadorian master paleomagnetic secular variation curve and conduct as many as possible archeomagnetic experiments on the extremely rich and long record of Ecuadorian archeological artefacts.

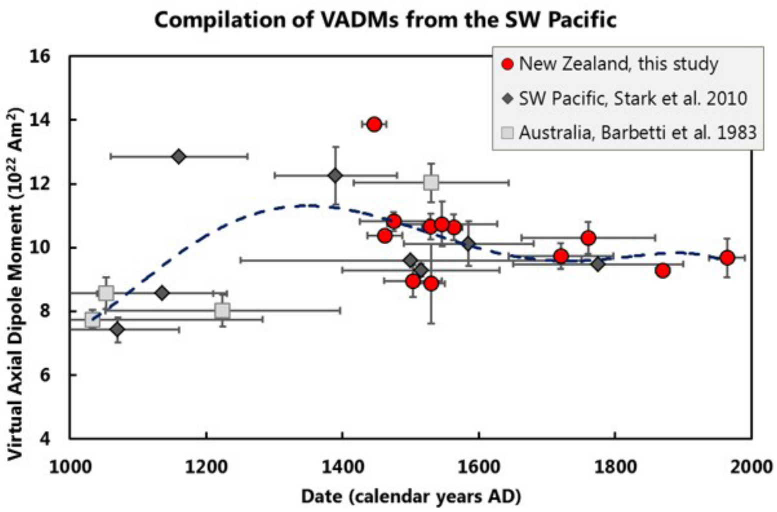

Figure 4. Variation of VADM from SW Pacific (Stark, 2011), Australian (Barbetti, 1983) and New Zealand (This study) archeomagnetic data for last 1000 years with a 5th order polynomial fit (blue dashed line).

4. Conclusions

The NZPSV1k master paleomagnetic secular variation curve and the first New Zealand archeomagnetic record, gathered during the past five years shows how combining the lake sedimentary data to high quality archeomagnetic data enhances our understanding of the behavior of the past Earth's magnetic field. The New Zealand archeointensity record, together with other data from Southwest Pacific, is consistent with global models back to 1590 AD. However, the data suggests more rapid variations and some unusually high palaeointensities before 1590 AD. More data from southern hemisphere and equatorial latitudes during this time is required in order asses the nature of this anomaly and other important questions about the past Earth's magnetic field more rigorously. Thereby our next step is to repeat this same process in Ecuador.

Acknowledgements: This work has been supported by the Royal Society of New Zealand Marsden grant.

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