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Two thousand years of archeointensity from West Africa

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ABSTRACT

This study presents 17 archeointensity estimates from Senegal and Mali, two neighboring countries in West Africa, for the period 1000 BCE to 1000 CE. The archeological artifacts used in this study were collected during the course of two separate projects, together spanning 22 years and across 8 separate excavations. A primary objective of this study was to get accurate dates, hence, only samples with independent age constraints from pottery style, detailed stratigraphy and ^{14}C dates were used. A total of 236 specimens from 63 samples were subjected to a double heating paleointensity experiment (IZZI method) from which 95 specimens were selected using a set of very strict selection criteria. The paleointensity results were corrected for differential cooling rate effects and remanence anisotropy. Additionally, we demonstrate the equivalence of using tensors derived from anhysteretic and thermal remanences for correcting remanent anisotropy of the specimens and use the former for the anisotropy correction. Our data show good agreement with the most recent paleosecular variation model but are lower than the pre-existing data, which are mostly from Egypt and Morocco. The presence of substantial non-axial-dipolar contributions in the region is evident when virtual axial dipole moments (VADMs) from the published literature are calculated for 20° latitudinal bands and compared with our data—the average VADM values show a distinct latitudinal gradient. A prominent feature of this dataset is an intensity high observed prior to 700 CE in both Senegal and Mali. Comparing this peak with existing records from regions further to the north suggests a small but significant temporal offset and is interpreted to be additional evidence for a geomagnetic field with a significant and rapidly changing non-axial-dipolar contribution.

1. Introduction

Archeomagnetism provides a unique window onto the changes in the Earth's magnetic field over the last few millennia. Compared to lavas, archeological artifacts are numerous, especially in more recent times. They can be used to construct regional reference curves, which can then, in principle, be used for the dating of other archeological artifacts from the region. The magnetic elements obtained from these items are also inputs for global field models such as the CALSxK generation of models (Korte and Constable, 2003, 2005, 2011), which often form the basis for answering fundamental geodynamo questions (e.g., Amit et al., 2011).

In spite of its potential, obtaining the full vector information from an archeological, or for that matter any kind of sample, is not a trivial task. While obtaining the direction of the ancient field is relatively simple, intensity measurements are more complicated because of the sensitivity of the experimental protocol to mineralogical alterations and domain states of the remanence carrier. Furthermore, there is no consensus yet on the experimental protocol and data reduction criteria and workers often use very different methods (Biggin, 2010). These could add to the scatter observed in an already impoverished dataset. Experimental difficulties and lack of access to suitable materials make the global coverage of data extremely heterogeneous with respect to space as well as time. As a result, the paleointensity data for the last 10 millenia are skewed, with the last two millennia contributing more than 50% of data. Moreover, the data are heavily biased to the northern hemisphere and there is a high concentration of data from Europe (see Fig. S1 of Supplementary data).

In an effort to contribute to the critical need for high quality data from the under-represented parts of the globe, we turn to the archeological findings from two areas of West Africa with rich Iron Age sites, the Middle Senegal Valley in Senegal and the Niger Valley in Mali (Fig. 1). West Africa, a geographically extensive region, comparable in size with the contiguous United States has sparse coverage in terms of archeomagnetic data (Kovacheva, 1984; Gomez-Paccard et al., 2012). The archeological samples in the present study are obtained from two groups of sites separated by 1200 km. These archeological artifacts were collected during two multi-phase, decade-long archeological projects by one of the authors.

In this study, we reconstruct the evolution of the geomagnetic field intensity in the region, between 1000 BCE and 1000 CE. The

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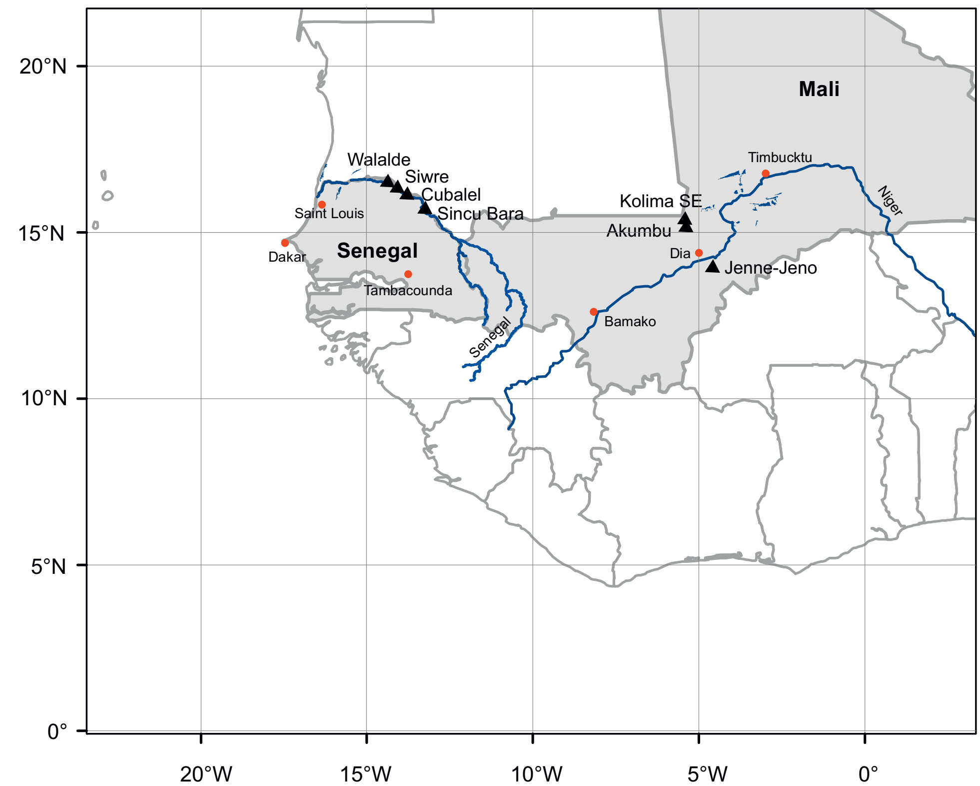

Fig. 1. Location of archeological sites in Senegal and Mali (black triangles). Important cities and ports are shown with red dots. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

location of the sites lies to the south of a pronounced geomagnetic flux patch over Europe during the time that might have influenced the samples in our sites (Korte and Constable, 2011). The passage of such a flux patch under a region would result in large non-axial-dipolar variations in the recorded paleointensity. Recently, it has been proposed that the 'archeomagnetic jerks' of Gallet et al. (2003), or the rapid changes in the field strength coupled with long-term directional changes in the field, are caused by the waxing and waning of geomagnetic flux patches in a region (Dumberry and Finlay, 2007; Amit et al., 2011). In this study, we find evidence for large non-axial-dipolar intensity variations, which may or may not be associated with the long-term directional changes of the geomagnetic field and are more likely to be the outcome of rapid paleosecular variation (PSV) in a region influenced by geomagnetic flux patches.

2. Archeological background

The artifacts used in this study are sherds of domestic, locally manufactured pottery that were collected over a course of two separate multi-year projects designed to gain insights into the development of iron-using societies along the Middle Niger Valley, Mali and the Middle Senegal Valley, Senegal (Fig. 1). In the rest of this section, we discuss briefly the archeological context of these two neighboring localities.

2.1. The Middle Senegal Valley samples

Between 1990 and 1999, five seasons of NSF-funded archeological research were conducted at a variety of sites in the central region of the Senegal Valley, where the historical polities of Takrur and Sila – first mentioned in an 11th century Arab chronicle – were thought to be located. The research aimed to investigate the origins and development of these early Sudanic polities. Prior archeological work in the Senegal Valley was sparse and of variable quality, so chronology-building was a primary goal of the research. The numerous settlement mounds, up to six meters in height, along the river between Cubalel and Waladé proved to be well-suited for this purpose, representing in each excavated instance between 3 and 10 centuries of domestic deposits that accumulated between 2600 and 1000 BP (Deme and McIntosh, 2006; McIntosh et al., in press). The pottery samples and radiocarbon dates used in this paper come from five of these mounds, viz., Waladé, Siwré, Cubalel C-1, C-3 and C-6, and one non-mound site, Sincu Bara, located 80 km downriver (Table 1).

During excavation, individual deposition contexts were identified and excavated separately. This maximized the likelihood that cultural materials and charred organics recovered from within each distinct context were deposited contemporaneously. All recovered materials from each discrete context were labeled to preserve the data on association and context.

For each excavation unit, stratigraphy is an important source of information on chronology, allowing reconstruction of the sequence of deposition for different contexts. These events may range from very brief (such as the scatter of ashes from a small hearth) to lengthy (e.g., the slow decay and wall melt of an abandoned wattle-and-daub house).

The stratigraphic sequence was complemented by the establishment of a ceramic sequence that recognized time-sensitive changes in the locally produced pottery assemblage. Petrographic analysis confirmed that the pottery was produced using local clay sources. Detailed analysis of ceramics from all excavated contexts resulted in identification of characteristic changes in pottery style through time (Fig. 2). This permitted the recognition of time-successive pottery phases within the mound deposits. Separate Phase sequences were defined for Waladé (Deme and