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ABSOLUTE GEOMAGNETIC FIELD INTENSITY IN GEORGIA DURING THE PAST 6 MILLENNIA

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ABSTRACT

We present new archaeointensity data from Georgia from ca. 3000 BCE to 1500 CE. Forty-eight potsherds and fired clays were subjected to Thellier-type paleointensity experiment using the IZZI protocol (Tauxe and Staudigel, 2004) with routine pTRM check. We observed an excellent agreement between samples collected from the same site, supporting the precision of the paleointensity working methodology. The new archeointensity data obtained in this study clarify some issue regarding the high variability period in Georgia. The results show a significantly high field maximum at 900 BCE, with VADM of about 160 ZAm^2, bounded by two low field minima around 1250 BCE and 400 BCE, with VADM of less than 60 ZAm^2.

Keywords: Archaeomagnetism, paleointensity, Georgia.

Introduction

Detailed information on the temporal and spatial evolution of the geomagnetic field is essential for understanding Earth's geodynamo. Hence, one of the key challenges in the geomagnetic research is obtaining high resolution records of the past geomagnetic field. The most detailed data comes from direct measurements, but such records span only over the past 400 years for the directional component (Jackson *et al*., 2000) and 170 years for the intensity component (Malin and Barraclough, 1982). Earlier periods necessitate the use of paleomagnetic methods. From the two parameters of the geomagnetic ancient field vector - intensity and direction - the intensity component is perhaps the most difficult to recover. The main reason is that suitable materials are hard to find, as they should retain a stable thermoremenent magnetization (TRM) residing exclusively in single-domain (SD) carriers. In addition, the paleointensity laboratory procedure is laborious with relatively low rate of success. Other complexities arise from remanence anisotropy and cooling-rate dependency, which can bias the results in a factor of up to 20%. The analysis of the paleointensity experiment data may be ambiguous, and there are no acceptable standards in the paleomagnetic community on the criteria for acceptable results, which add another difficulty. Above all these experimental issues dating uncertainties should be carefully evaluated.

Given these complexities, it may not seem surprising that different paleointensity datasets can show some discrepancies and a certain level of noise in a collection of data is expected. This problem compounds when trying to assemble a regional or global archaeointensity curves by compiling different datasets constructed using different laboratory techniques and data analysis guiding principles. This issue can be overcome by gathering all the raw measurements in one global database – the MagIC (http://earthref.org/MAGIC/). This allows all researchers to re-interpret and re-compile the paleointensity data based on the behavior in the paleointensity experiment rather than published summary tables. Here we present new archaeointensity data from Georgia from ca. 3000 BCE to 1500 CE. The study is designed to investigate puzzling trends in the published data of Georgia. Previous studies from Georgia yielded large amount of data, but with a considerable amount noise (fig. 1). Screening out these data for the most reliable and accurate datapoints is not an easy task due to the reasons listed above and the fact that the actual measurement data of these data is unavailable. Therefore, we designed a survey aimed at revising the previous data using more modern experimental techniques and data analysis methodologies. In addition, we make our measurements available in the MagIC database for the use of other researchers.

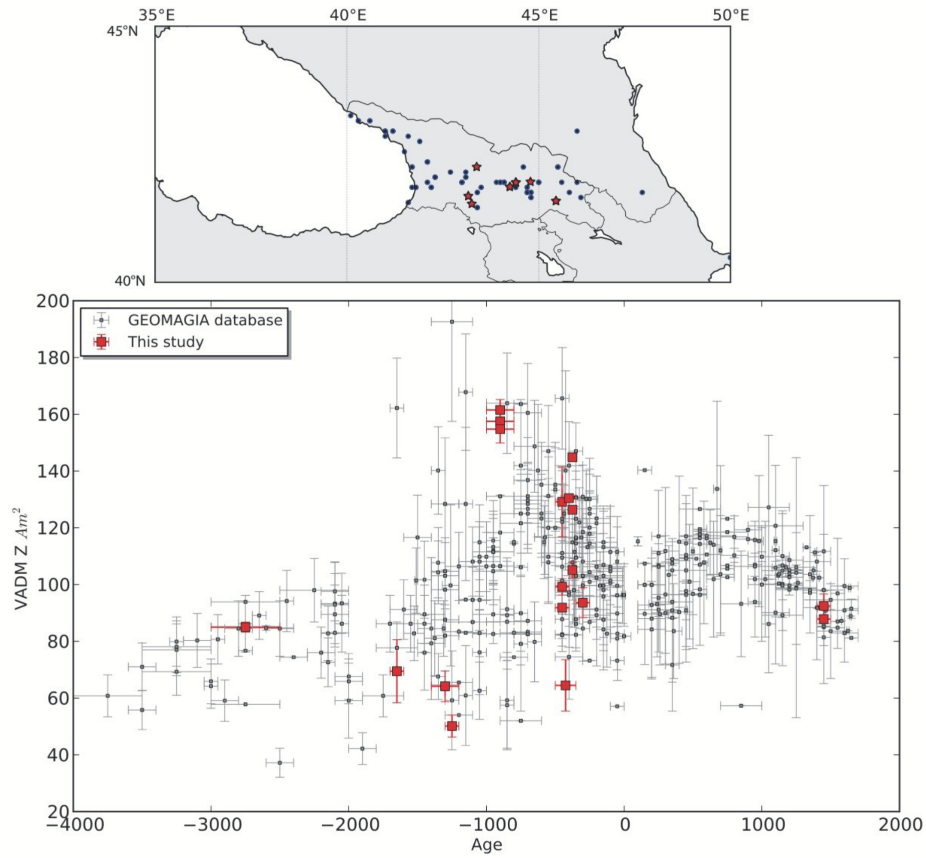

Figure 1. Top: map of Georgia showing the sampling sites in this study (red stars) and locations of previous studies. Bottom: Paleointensity curve displayed as Virtual Axial Dipole Moment (VADM). Previous data was obtained from the GEOMAGIA database (Korhonen *et al*., 2008). Red symbols are preliminary results from Georgia.

Main Results

From the inspection of Figure 1 we can roughly divide the paleointensity trends in the previous data into three main events: From 4000 BCE to 2000 BCE there is a progressive increase cut by a sharp drop at about 2000 BCE; From 2000 BCE to around 0 BCE the data demonstrate both very low and very high field values with relatively large variability. From around 0 BCE to present the data as a whole converge to a clear picture with two local lows around 0 BCE and near present, and one local high around 800 CE. The period between 2000 BCE to around 0 BCE is the main focus of our study. Forty-eight potsherds and fired clays were analyzed in the paleomagnetic laboratory of Scripps Institution of Oceanography, University of California San Diego. Each sample was cut into 3-9 specimens, which were subjected to Thellier-type paleointensity experiment using the IZZI protocol (Tauxe, and Staudigel, 2004) with routine pTRM check (Coe *et al*., 1978). Additional procedures included anisotropy of TRM (ATRM) measurements and cooling rate dependency experiments. The data was analyzed using the *Thellier GUI* program (Shaar and Tauxe, 2013; http://sorcerer.ucsd.edu/ThellierGui/) that allows an automatic and subjective interpretation using paleointensity statistics as selection criteria. We analyzed the data using the following criteria at the specimens level (See Shaar and Tauxe 2013 and Appendices within for details): FRAC ≥ 0.8; b ≤ 0.10; MAD ≤ 5; DANG ≤ 10; N_{pTRM_cheks} ≥ 2. Sample means were calculated using at least three specimens. Typical behavior of a successful specimen is shown in Figure 2.

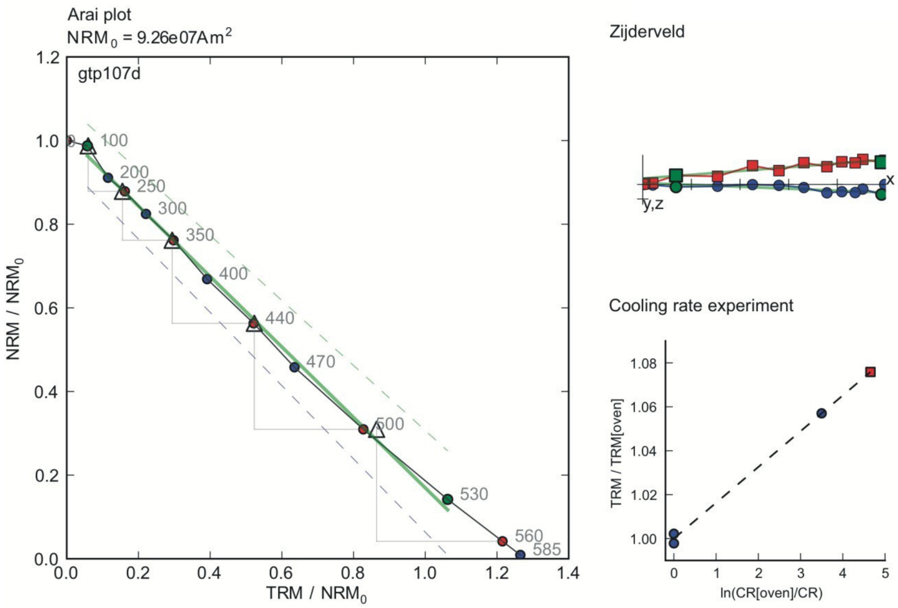

Figure 2. Typical successful behavior in the paleointensity experiment. Arai plot: Blue (red) circles are the ZI (IZ) steps in the IZZI protocol, triangles are pTRM checks. The least squares line is shown in green, the bounds of for SCAT parameter (Shaar and Tauxe, 2013) are shown as dashed line. Zijderveld plot: red (blue) symbols are x-y (x-z) projection in the specimen coordinates where the x-axis is pointing to the direction of the NRM. Cooling rate experiment: blue symbols show the normalized TRM versus log of the inverse normalized cooling rate. Red symbol is extrapolation for the assumed ancient cooling rate (yielding in this case overestimation of 8%).

The final interpretations are listed in Table 1, demonstrating excellent agreement between samples collected from the same site, supporting the precision of the paleointensity working methodology. The new data is displayed in Figure 1 in red symbols, and other published Georgian paleointensity data that appear in the GEOMAGIA database (Korhonen *et al*., 2008) are shown in black. In general, there is a good agreement between the new and the previous data. However, the new data clarify some issue regarding the high variability period in Georgia. The results show a significantly high field maximum at 900 BCE, with VADM of about 160 ZAm^2, bounded by two low field minima around 1250 BCE and 400 BCE, with VADM of less than 60 ZAm^2. Our data shows that the decay of the field from 900 BCE was not steady. Instead, we notice large variability. To further constrain the details of this activity more high quality and well-dated data is required. A comparison of the Georgian paleointensity data with regional curves from nearby location (Northern Levant: Genevey *et al*., 2003; Gallet *et al*., 2008; Southern Levant: Shaar *et al*., 2013; Bulgaria: Kovacheva *et al*., 2009; Greece: De Marco *et al*., 2008) show some similarities in the shapes of the paleointensity curves including a high field maximum during the first millennium BCE. However, we notice some phase shifts between locations that call for a deeper inspection of the spatial variability of the field on a continental scale.

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Table 1. Archaeointensity interpretations [a]

Location	Sample name	Lat, Long	Age range	Number of specimens	B ± σ (μT)	VADM ± σ (ZAm^2)
Aspindza 1	gas101	41.57,43.25	-1700 to -1600	6	38 ± 6.1	64.5 ± 10.3
Atskuri 1	gat102	41.72,43.16	1400 to 1500	6	50.8 ± 1.9	86 ± 3.2
Atskuri 1	gat104	41.72,43.16	1400 to 1500	3	48.3 ± 0	81.8 ± 0
Grakliani gora 1	ggg101	41.99,44.40	-400 to -350	5	74.9 ± 0.4	126.6 ± 0.6
Grakliani gora 1	ggg102	41.99,44.40	-400 to -350	4	62.3 ± 1.6	105.3 ± 2.7
Grakliani gora 2	ggg202	41.99,44.40	-400 to -350	5	85 ± 0.2	143.6 ± 0.3
Grakliani gora 3	ggg301	41.99,44.40	-400 to -500	5	76.6 ± 7.3	129.4 ± 12.4
Grakliani Hill 2	ggh201	41.99,44.40	-500 to -350	6	34.8 ± 5.5	58.8 ± 9.3
Grakliani Hill 4	ggh401	41.99,44.40	-450 to -350	6	71.1 ± 0.1	120.1 ± 0.1
Grakliani Hill 5	ggh501	41.99,44.40	-350 to -250	6	54.3 ± 2.6	91.8 ± 4.4
Khovle 1	gkv101	41.91,44.24	-1000 to -800	4	91.1 ± 0.1	154.1 ± 0.2
Khovle 1	gkv102	41.91,44.24	-1000 to -800	7	88.6 ± 0.2	149.8 ± 0.4
Khovle 1	gkv103	41.91,44.24	-1000 to -800	7	87.4 ± 4.5	147.9 ± 7.5
Ortsheni necropolis 1	gon102	42.00,44.78	-1300 to -1200	4	29.7 ± 2.3	50.2 ± 3.9
Sachkhere 1	gsa101	42.30,43.38	-3000 to -2500	6	46 ± 1.2	77.5 ± 2.1
Tsminda Pchani 1	gtp107	41.63,45.45	-500 to -400	5	59.4 ± 2.6	100.7 ± 4.5
Tsminda Pchani 1	gtp108	41.63,45.45	-500 to -400	4	51.7 ± 0.9	87.7 ± 1.6
Tsminda Pchani 2	gtp202	41.63,45.45	-1400 to -1200	3	36.6 ± 1.3	62.1 ± 2.3

[a] Results are given as sample's mean. The results are calculated using the automatic procedure of the Thellier–Gui program (Shaar and Tauxe, 2013, http://sorcerer.ucsd.edu/ThellierGui/) using the following acceptance: FRAC ≥ 0.8; β ≤ 0.10; MAD ≤ 5; DANG ≤ 10; NpTRM_cheks ≥ 2; N_{sample} ≥ 3.