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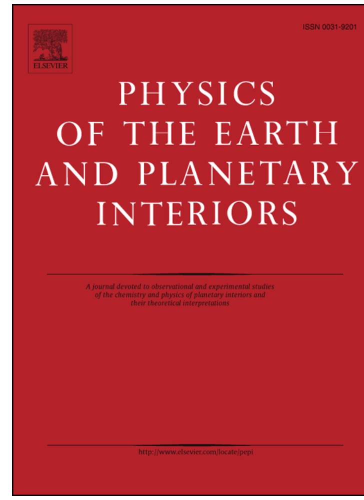

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New archeointensity data from NW Argentina

(1300-1500 AD)

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Abstract

A good characterization of the geomagnetic field strength at centennial to millennial time scales in the Southern Hemisphere is particularly crucial to disentangle the long-term evolution of the South Atlantic Anomaly (SAA), an intriguing geomagnetic feature currently observed at the Earth´s surface. Here we present 59 new archeointensities obtained from four well-dated groups of potteries with ages ranging between 1300 and 1500 AD and collected in Northwest Argentina. The new data were obtained in accordance with the Thellier paleointensity method including partial thermoremanent magnetization (pTRM) checks and TRM anisotropy and cooling rate corrections. We have also performed a comparative study of the efficiency of magnetic the susceptibility, ARM and TRM anisotropy tensors to correct the TRM anisotropy effect upon intensity estimates. Our results suggest that the magnetic susceptibility tensor systematically underestimates the TRM anisotropy effect by 10 to 30 %. Our new data, together with a selection of selected archeointensities already published, confirm that the decrease of the geomagnetic field intensity in South America started around 1600-1650 AD, due to the arrival of the SAA.

1 Introduction

Paleomagnetic data suggest that the geomagnetic field, generated by a convective dynamo operating in the Earth´s electrically conducting fluid outer core, has existed for more than four billion years (Tarduno et al., 2015a). However, whereas changes of the geomagnetic field over the last centuries are rather well known thanks to historical and geomagnetic field observatory data (Jackson et al., 2000), the uncertainties arising from hemispheric and temporal paleomagnetic sampling biases limit the robustness of geomagnetic field reconstructions for older times. Even the most recent Holocene geomagnetic field models provide significantly different patterns of temporal variation of the dipolar and non-dipolar terms of the Earth´s geomagnetic field (e.g. Pavón-Carrasco et al., 2014a; Constable et al., 2016). As a consequence, the acquisition of new indirect observations derived from archeo- and paleomagnetic studies is crucial to disentangle the real variation of the geomagnetic field in the past. This requirement is particularly important for South America since this region contains one of the most intriguing features of the geomagnetic field at the Earth´s surface: the South Atlantic Anomaly (SAA).

The SAA is a region currently located at Southern Brazil where anomalous low field intensity values are observed due to the presence of a strong non-dipolar field. This anomaly has been commonly attributed to reversed flux patches at the core mantle boundary present below the South Atlantic. This feature is not only characteristic of the present field but also for the last 400 years (Jackson et al., 2000; Hartmann et al. 2011). Recent studies suggest that this anomaly is a persistent feature of the geomagnetic field for at least the last millennium but probably also for a longer time interval (Tarduno et al., 2015b; Shah et al., 2016). Whatever the exact long-term trend, there is little doubt that the decrease of the axial dipole moment observed in historical times is related to the evolution of the reversed flux patches in the Southern Hemisphere and, hence, to the SAA history (e.g. Hulot et al., 2010; Finlay et al., 2016; Constable et al., 2016; Pavón-Carrasco and De Santis, 2016; Terra-Nova et al., 2017). A good knowledge of the geomagnetic field in the Southern Hemisphere is thus crucial to place into a long-term temporal perspective the rapid decay of the dipole moment observed nowadays.

In this context, new high-quality data from the Southern Hemisphere are clearly needed. Despite the substantial efforts made over recent years providing new paleomagnetic data for South

America (Poletti et al., 2016 and references therein), our view of past geomagnetic field changes in this area is still rather vague. In this paper, we focus our effort to address this challenge and present new archeomagnetic data obtained from a set of pottery fragments collected in the Puna of Jujuy (NW Argentina). Our study also highlights that the magnetic susceptibility (and in some cases but in a lesser extent also the anhysteretic remanent magnetization) anisotropy tensors are not good proxies to correct the TRM anisotropy effect upon archeointensity estimates. As already pointed out before by Poletti et al. (2016), the vast majority of the previous published South American archeointensities should be discarded for geomagnetic field interpretation since they were not obtained following modern standards of quality. Finally, selected high-quality data from South America and global geomagnetic field reconstructions are used to discuss the origin and behavior of past regional intensity fluctuations in the area.

2 Methods

Modern humans colonized South America during the Pleistocene-Holocene transition. There is agreement that the human occupation of the Puna of Jujuy, the northern end of the Argentinean northwest, dates back to the early Holocene. The development of ancient hunter-gatherer societies continued for several millennia, with human groups subjected to marked climatic variations fluctuating between periods of high humidity (e.g. during the early-Holocene; Lupo et al., 2016; Núñez et al., 1995-96; Schäbitz et al., 2001) followed by extreme dry events related to a global temperature increase (e.g. the Optimal Climate in boreal latitudes; Grosjean, 2001; Núñez et al., 2013) that produced a sharp decrease of human occupation in the area. From ca. 3000 BP, climatic conditions comparable to those prevailing today favored the development of agro-pastoral societies of permanent residence. These societies developed advanced new technologies such as, for example, the manufacture of potteries. Subsequently, a growing complexity appeared, a process that culminated during the so-called *Período Intermedio Tardío* (Núñez, 2006), and dated from ca. 1000 AD to the annexation to the Inca Empire, about one century before the Spanish conquest in 1536 AD (Tarragó, 2000).

Here we present the study of four groups of pottery fragments (POPI, CASU, TUS2 and TUCI) collected in three different pre-hispanic agro-pastoral settlements of the highlands of the Jujuy province in northwest Argentina (Figure 1). The archeological sites are located near freshwater resources where remains of different human settlements were studied in the framework of different archeological investigations (Albeck and Zaburlin, 2008). Archeological evidence indicates that the four groups correspond to the *Período Intermedio Tardío*. Several radiocarbon analyses, calibrated using the IntCal 13 curve (Reimer et al., 2013), allow the establishment of an independent and more precise chronology for our studied collection, between the 14th century AD and the first half of the 15th century AD (Table 1).

%% Insert here Figure 1 %%

The collected potteries were analyzed in the paleomagnetic laboratory of Géosciences-Rennes, France. The fragments were cut into 2-4 specimens of about 1 cm, that were introduced in quartz cylinders. Remanent magnetization was measured using a 2G cryogenic magnetometer with a degausseur system, in a zero-field chamber. Anisotropy of magnetic susceptibility (AMS) was measured with a KLY3 Agico spinner kappabridge. Between two and four specimens per fragment were subjected to the classical Thellier experiment (Thellier and Thellier, 1959) following the same methodology explained in our previous studies (e.g. Gómez-Paccard et al., 2006, 2012, 2016). The intensity of the laboratory field was fixed at 35 μT and the field was applied in the direction perpendicular to the plane of flattening of the studied potteries (z direction). Magnetic alteration was checked by performing pTRM checks every two temperature steps. The TRM anisotropy tensor was determined by measuring the laboratory TRM acquired following six different directions (-x, +x, -y, +y, -z and z in sample coordinates) at the temperature for which about 70% of the initial natural remanent magnetization (NRM) was lost. At the same temperature, cooling rate dependence was estimated from three additional measurements, two corresponding to 1.5 h of cooling and one to 24 h (see Gómez-Paccard et al., 2006 for further details). We assume an ancient cooling of about one day although no strong archeological constraints are available to determine the real cooling time of our potteries during their manufacture. The selection criteria used to check the reliability of the intensities obtained at the specimen level are similar to those applied in Gómez-Paccard et al. (2016). Only linear NRM-TRM diagrams corresponding to well defined straight lines going to the origin in the Zijderveld plots are considered. The differences between the original pTRM and the pTRM check must be lower than 10% of the total TRM. We fixed a limit of 50% for the fraction of the initial NRM involved in archeointensity determination (f parameter; Coe et al., 1978). Finally, a maximum value of 5° was assigned to the maximum angular deviation (MAD; Kirschvink, 1980) and the deviation angle (DANG; Pick and Tauxe, 1993). Furthermore, we also calculate the ratio of the standard deviation of the slope to the absolute value of the slope (ß) and the curvature parameter k (Paterson, 2011). In addition, the MS, ARM and TRM anisotropy tensors TRM were determined on 18 selected specimens. Finally, different rock-magnetic measurements were carried out at the paleomagnetic laboratory of the Universidad Complutense de Madrid (Spain) on selected specimens. This includes susceptibility versus temperature curves, acquisition of isothermal remanent magnetization (IRM) and back-IRM curves, and hysteresis loops.

3. Results

Initial NRM intensities and bulk susceptibilities (χ) of the studied specimens define Königsberger ratios (calculated as Q = NRM/χ * H, with H = 39 Am^{-1}) between 5 and 100. These values indicate a good capability to maintain stable remanence and are typical of well-baked argillaceous materials (e.g. Jordanova et al., 2003; Catanzariti et al., 2012). This suggests a thermomagnetic origin for the NRM acquired by our samples (Figure 2).

%% Insert here Figure 2 %%

Rock-magnetic results (Figure 3a-d) indicate that the magnetic mineralogy is dominated by magnetic grains characterized by low-coercivity phases and Curie Temperatures, estimated using the second derivative method of Tauxe (1998), in the range 510-580º C (except for two specimens), such as magnetites and titanomagnetites with low titanium contents.

%% Insert here Figure 3 %%

Thellier experiments were performed on 82 specimens. Fifty nine of them, corresponding to 31 different pottery fragments, have been retained to estimate past geomagnetic field intensities. They all respect the selection criteria detailed in the previous section (Figure 4a-e). The q values obtained for our retained specimens vary typically around 50, while β and k are typically lower than 0.02 (see Table S1 and Figure S1 in the Supplementary Material online). The straight lines observed in the NRM-TRM diagrams and the generally low values of k (see Figure S1e) exclude a significant effect of multidomain grains behaviour. These (characteristic) components are interpreted as the TRM acquired during the manufacture of the potteries. The other specimens corresponding to a complex behaviour with two components of magnetization in the Zijderlveld plots (Figure 4f) were rejected.

%% Insert here Figure 4 %%

Our measurements show that the TRM anisotropy effect upon paleointensity estimates is very high for the majority of the studied specimens, with differences between the uncorrected and corrected intensity up to 50% (Figure 5 a-d). The cooling rate effect is generally low for the studied collection (Table S1). Our four mean archeointensities, calculated using the weighting approach proposed by Prévot et al. (1985), indicate that during the 14^{th} and 15^{th} centuries AD field intensity in NW Argentina was between 41 and 49 μT (Table 1).

%% Insert here Figure 5 %%

4 Discussion

4.1 Cautionary note on TRM anisotropy correction

Different effects, such as magnetic alteration, magnetic anisotropy or the presence of multidomain magnetic grains have not been systematically considered when geomagnetic field strength is estimated from paleomagnetic measurements. Together with dating uncertainties this fact produces important inconsistencies and internal discrepancies on both regional (e.g. Tema et al., 2012; Cai et al., 2017; Shaar et al., 2017; Molina-Cardín et al., 2018) and global (e.g. Pavón-Carrasco et al., 2014a; Constable et al., 2016) data sets. Our results (see section 3) confirm that the correction of the TRM anisotropy effect is an essential requirement when paleointensity data are derived from highly anisotropic archeological objects, such as the potteries studied here. The TRM anisotropy is commonly interpreted as reflecting a preferential alignment of magnetic grains caused by a stretching of clay during the manufacturing process (Aitken et al., 1981; Genevey et al., 2008). As a result, the easy planes of magnetization correspond to the planes of flattening of potteries as it is clearly observed in our data (see Figure 5c).

In the literature, the effect of magnetic anisotropy on paleointensity estimates has been evaluated using different approaches (see Genevey et al., 2008 for a review). The approach followed here is to determine the TRM anisotropy (ATRM) ellipsoids to directly correct both the NRM and the laboratory TRM at each temperature step (Veitch et al., 1984). In some studies, the ATRM has been evaluated through the determination of the anisotropy of the anhysteretic remanent magnetization (AARM) or the anisotropy of the magnetic susceptibility (AMS), which were considered as proxies for the ATRM tensor. In order to investigate if these two approaches are valid on our samples, we obtained the AMS, the AARM, and ATRM ellipsoids of 18 fresh specimens following the procedure explained in Text S1 (Supplementary Information online). The principal axes (K_{max}, K_{int} and K_{min}) of the different tensors and their corresponding orientations were obtained and plotted in Figure S2 (see also Table S2). The results show that even if the orientation of the principal axes of these tensors are very close, their shapes are different. They confirm the observations of previous studies performed on baked clays (Chauvin et al., 2000).

As a second test, we imparted a TRM to the 18 specimens by applying a magnetic field of 35 μT perpendicular to the planes of flattening of the potteries and we then correct the direction and the intensity of these laboratory TRMs by using the MS, ARM and TRM anisotropy tensors (here and after AMS, AARM and ATRM tensors). For each specimen, we have compared the intensity of the laboratory TRM corrected by the AMS and ARM tensors with the one obtained using the TRM tensor. The results are plotted in Figure 5e. They indicate that when the AMS tensors are used the TRM intensity is systematically underestimated (with biases that can reach 30%). On the contrary, corrections performed with the ARM tensors can under- or over- estimate the TRM intensity, with biases ranging between 8 and -20%. These results suggest that archeointensity data corrected for the ATRM effect using the AMS tensor as a proxy are systematically biased toward lower values. Although important errors (around 20%) can also be introduced if the ARM tensor is used, in general the observed biases are lower than 10%.

As it is shown in Figure 5 a-b, the correction of the TRM anisotropy effect via the direct determination of the ATRM tensor is very effective since very similar intensity values are obtained after the ATRM correction. Moreover, the ATRM effect can be different on two specimens from the same pottery fragment (see also Table S1), as already suggested before (e.g. Genevey et al., 2008; Gómez-Paccard et al., 2008). For this reason, we would like to highlight, as already pointed by Poletti et al. (2016), that mean fragment intensities cannot be calculated by averaging the estimations obtained from six sister specimens remagnetized following six orthogonal directions. This procedure was used in some previous studies (e.g. Morales et al., 2009; Goguitchaichvili et al., 2012) but, it should be discarded in future studies.

4.2 The South American database

Modeling the geomagnetic field behavior over the past few millennia requires the use of both directional and intensity archeomagnetic data. While the acquisition of archeomagnetic directions is relatively straightforward, archeointensity determination is a laborious, complex and time-consuming task. As a consequence, there is a widespread lack of consistent coverage of archeointensity data in both time and space, with data gaps most pervasive in some areas. This is for example the case for South America, as already noticed by Poletti et al. (2016). Although considerable efforts are being undertaken during the last few years (e.g. Roperch et al., 2014, 2015; Goguitchaichvili et al., 2011, 2012, 2015; Hartmann et al., 2010, 2011; Poletti et al., 2016), only 225 mean archeointensities (about 7 % of the total database) are nowadays available for this region. This includes data from Ecuador, Bolivia, Peru, Brazil, Chile and Argentina with ages ranging between 3200 BC and 2000 AD (Table S3). The Virtual Axial Dipole Moments (VADM) derived from this dataset show very large dispersions (Figure S3). For example, VADM values between $5 \cdot 10^{22}$ and $18 \cdot 10^{22}$ Am^2 are observed around the 4-5th centuries AD. This high dispersion is obviously related either to some low-quality data that do not fulfill modern standards of quality (Genevey et al., 2008; Gómez-Paccard et al., 2012; Paterson, 2011) and/or to errors in the age determination of the studied archeological materials. The majority of the South American archeointensities have been derived from highly anisotropic objects (potsherds and ceramics) for which TRM anisotropy corrections were not performed at the specimen level or applied in an inefficient way (see also Poletti et al., 2016 for further details). However, we would like to note that, contrary to the global database, none of the previous archeointensity values available for South America have been derived from Thellier derived experiments corrected for the TRM anisotropy effect via the ARM anisotropy tensor determination. In addition, 57% of the available mean archeointensities were computed using less than four specimens. This, together with possible dating errors, easily explains part of the large dispersion observed in the South American dataset.

In order to disentangle the real geomagnetic field intensity trend in South America we re-evaluate the South American dataset by applying a set of quality criteria similar to those explained in Pavón-Carrasco et al. (2014b). The selected dataset includes data derived from Thellier or Thellier-derived techniques including pTRM checks and ATRM corrections performed at the specimen level and using the TRM anisotropy tensor if potteries or ceramics were studied. Moreover, a minimum of 4 specimens to compute the mean intensity value is required. Finally, we only accepted intensity estimates obtained in a temperature interval comprising the ATRM correction. This procedure, although it may be somewhat restrictive, at least assures the reliability of the selected intensity values. The compiled and complete South American dataset together with the associated information used to classify the different data can be found in Table S3.

It appears that few archeointensities (43 in total) from South America can be considered as reliable mean intensities according to our criteria: 2 from Ecuador (Bowles et al., 2002), 7 from Argentina (3 from Goguitchaichvili et al., 2011, and 4 from this study), 8 from Chile (Roperch et al., 2014, 2015) and 26 from Brazil (Hartmann et al., 2010, 2011; Poletti et al., 2016). The ages corresponding to this high-quality compilation range between 3000 BC and 2000 AD, but all of them (except one data from Ecuador and two from Chile) correspond to the last 1000 years. We would like to highlight that our selected data set is almost identical to one compiled by Poletti et al. (2016). This suggests that the paleomagnetic community is reaching some kind of consensus since our first claim for the need to perform a preselection of archeointensity data before geomagnetic field interpretation purposes (Chauvin et al., 2000, Gomez-Paccard, 2008).

4.3 Geomagnetic field intensity trends in South America over the last millennium

Archeointensity data from Argentina covering the last millennium are plotted in Figure 6. The low number of high-quality data for this region is clearly hampering a detailed analysis of past geomagnetic field variations over this period. However, our results together with previous selected data from Argentina suggest that the geomagnetic field intensity in this region was around two times higher than the present-day value until at least 1450-1500 AD (Figure 6). According to selected archeointensity data, the geomagnetic field intensity decreased in Argentina during the 14^{th} century by ~ 5 μT/century and increased during the 15^{th} century with a similar rate (Figure 6). The intensity predictions computed by recent global models based on archeomagnetic data (ARCH3k.1, Korte et al., 2009; and SHA.DIF.14k, Pavón-Carrasco et al., 2014a) show lower variations rates.

In order to have a general view of geomagnetic field intensity variation in South America, we have estimated the VADM corresponding to the available high-quality intensities (Figure 7). They were compared with the dipole moment derived from the global geomagnetic models mentioned before as well as with the axial dipole evolution GMAG9k based on temporal and spatial averaging of the global intensity database (Usoskin et al., 2016). Our results confirm that the strongest discrepancies between observed VADMs and predicted dipole moments are observed after 1600-1650 AD (see also Hartmann et al., 2011; Poletti et al., 2016). These discrepancies reflect both the decreasing of the dipole moment and the increasing contribution of non-dipolar sources, both phenomena contributing to the SAA.

%% Insert here Figure 7 %%

5 Conclusion

We obtained 59 new archeointensities for Northwest Argentina, obtained from the archeomagnetic study of four well-dated groups of potteries corresponding to the14th and 15th centuries. Our study demonstrates that the AMS (and in some cases also the AARM) tensor is not an efficient proxy to correct for the TRM anisotropy effect upon archeointensity estimates. With this in mind, and in agreement with Poletti et al. (2016), we have selected the most reliable South American archeointensities. Our new archeointensity results together with selected data indicate that, over the last millennium, the geomagnetic field intensity in Argentina was around two times higher than the present-day value until 1450-1500 AD. Comparison with different global geomagnetic field reconstructions confirms that important differences between the VADMs and dipole moment trends occurred only after ~1650 AD. Weaker dipole moment and stronger non-dipolar contributions explain the low field intensity values observed in South America due to the arrival of the SAA. The low number of high-quality archeointensities (and paleomagnetic directions) calls, however, for the acquisition of additional data for better constraining the dynamical behavior of geomagnetic field in South America.

Acknowledgements and Data Statement

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Supporting Information

Supporting information related to this article can be found online.

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Figures

Figure 1. *a) Map of South America showing the location of the archeological sites where the material was recovered (orange dot). Locations of previous data (see text for a description) are also indicated. b) Image of some of ceramic shards corresponding to the TUS2 and POPI collections (see Table 1 for details on the studied collections).*

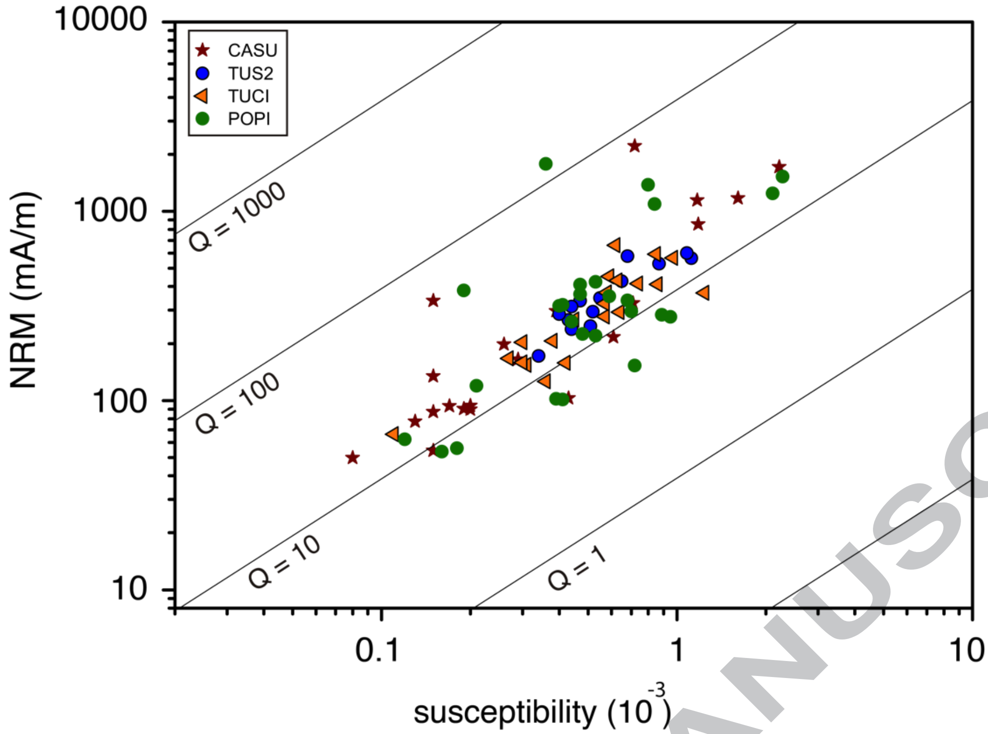

Figure 2. *Intensity of the Natural Remanent Magnetization (NRM) versus bulk susceptibility (10^{-3} SI). Lines indicate constant Köenigsberger ratios (Q).*

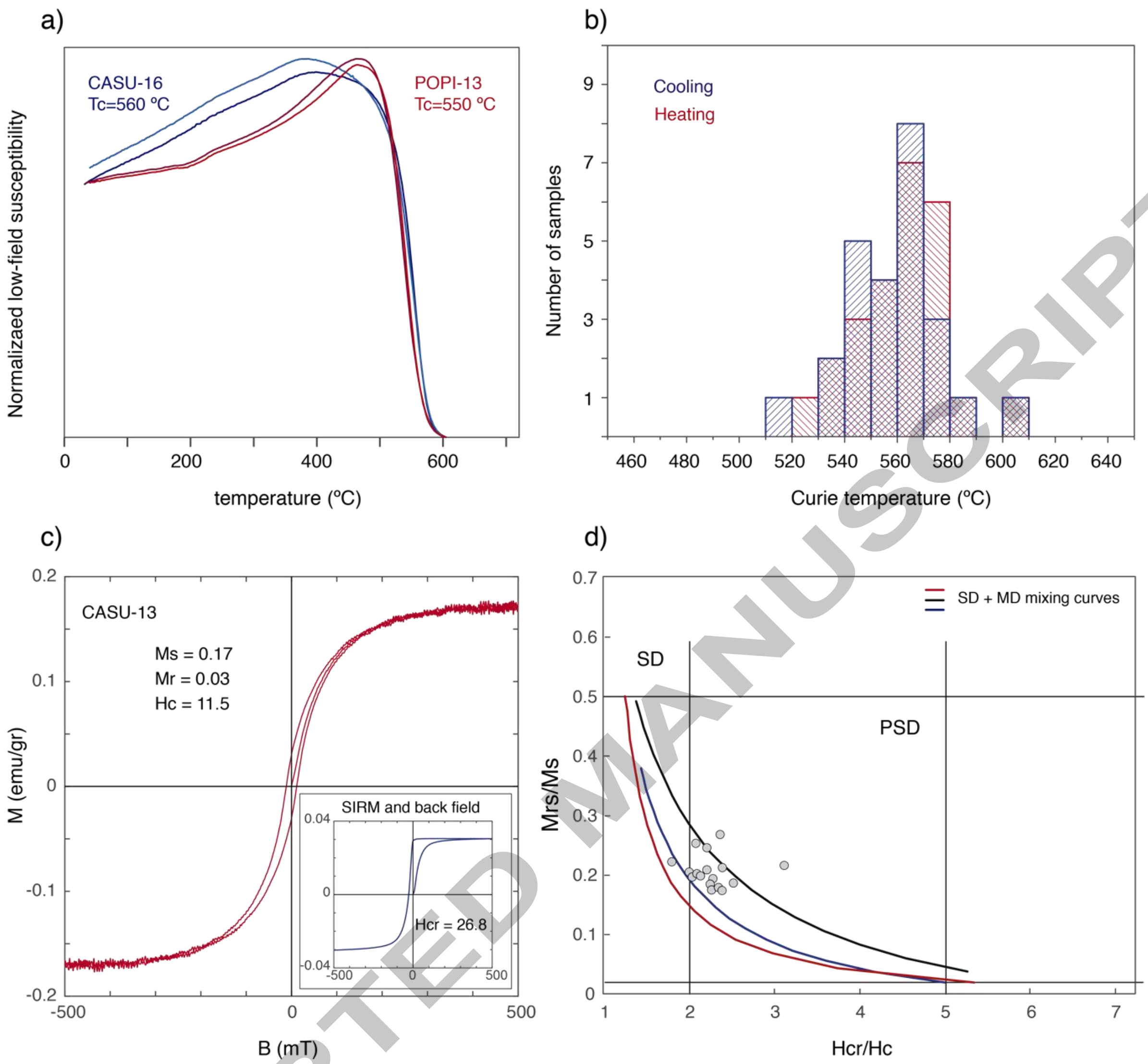

Figure 3. *Rock magnetic properties. a) Normalized susceptibility versus temperature curves from two representative samples. b) Curie temperatures derived from both the heating and cooling branches of susceptibility versus temperature curves. c) Hysteresis curve and isothermal remanence (IRM) and back-field IRM curves for a representative sample. d) Day-plot of magnetization and coercivity ratios. The lines indicate the two SD and MD theoretical mixing curves of Dunlop (2002) and the SD + MD mixing curve also from Dunlop (2002) but based on data from Parry (1980, 1982).*

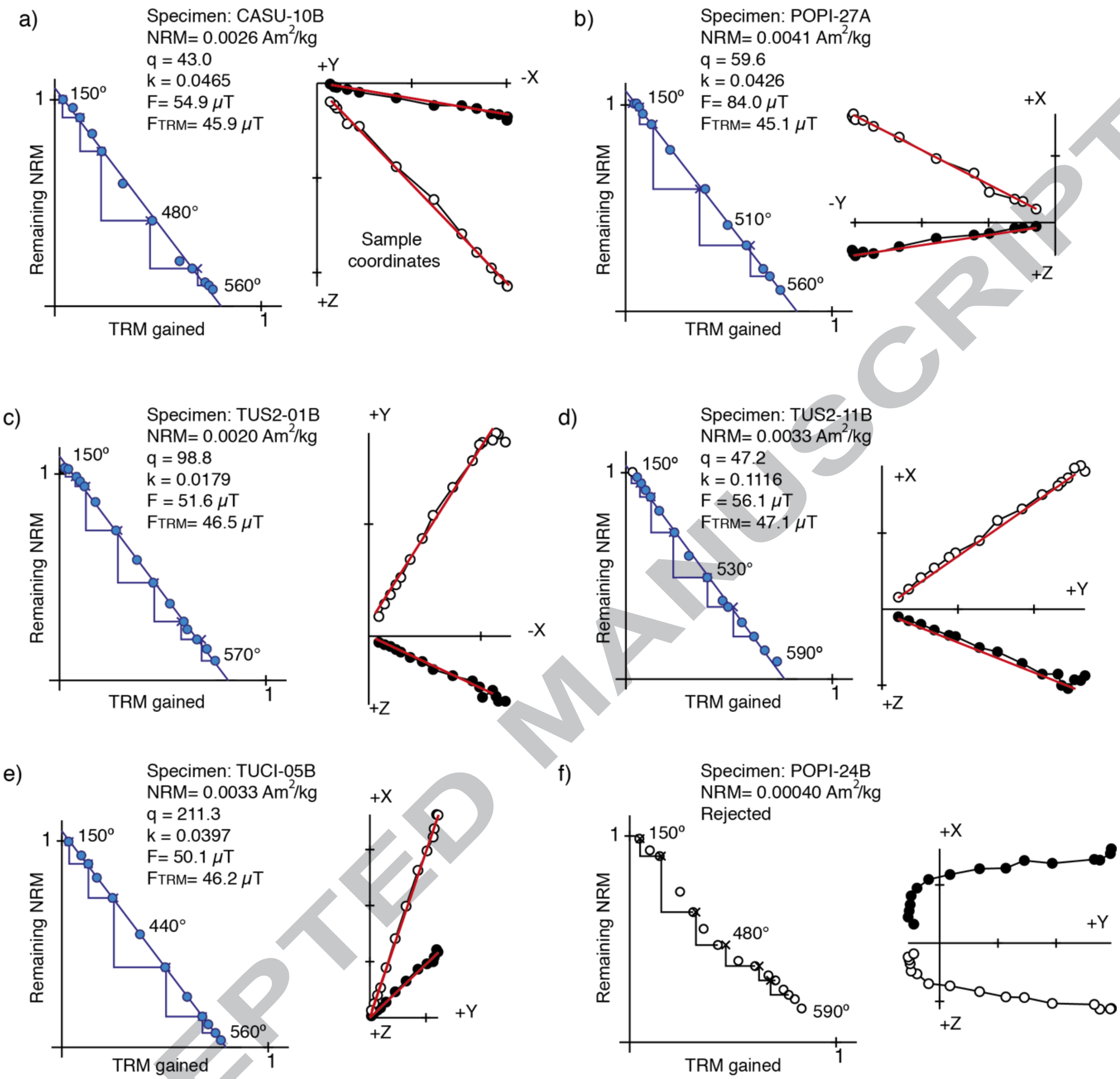

Figure 4. *Representative examples of Thellier archeointensity experiments. Examples of accepted (a-e) and rejected (f) results. Temperatures are in degrees Celsius. Solid circles in the NRM-TRM plots indicate the temperature steps used for intensity determination. The NRM-TRM diagrams are shown together with Zijderveld plots, for which open (solid) circles indicate projections on the vertical (horizontal) plane. The initial NRM, the q factor, parameter k (defined by Paterson, 2011), and the intensity value before (F) and after (F_{TRM}) TRM anisotropy correction are indicated.*

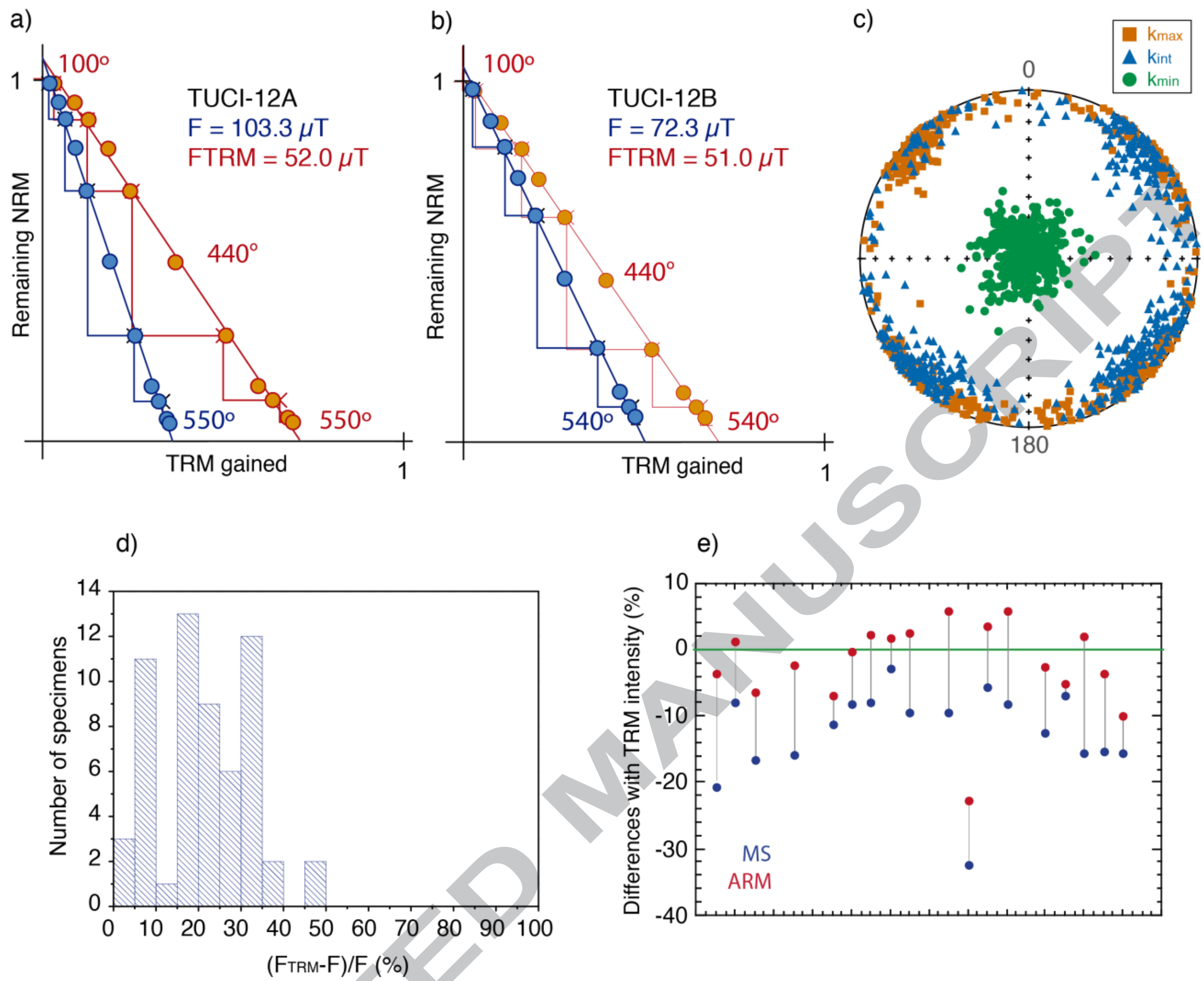

Figure 5. *a-b) Comparison of the NRM-TRM diagram obtained before (F) and after (F_{TRM}) TRM anisotropy correction for two sister specimens from the same pottery fragment. c) Stereographic projection, in sample coordinates, of the direction of the principal axis of the TRM ellipsoids for individual specimens of the four studied collections. K_{max}, K_{int} and K_{min} are the principal, intermediate and minimum axes, respectively. The easy planes of magnetization correspond to the planes of flattening of the pottery fragments. d) Differences between TRM corrected (F_{TRM}) and uncorrected (F) estimates of geomagnetic field strength. e) Differences between the intensities of a laboratory TRM after correction using the TRM, MS and ARM tensors. The values (in %) are calculated as ($TRM_{AMS\ or\ ARM}$ – TRM_{TRM})/ TRM_{TRM}.*

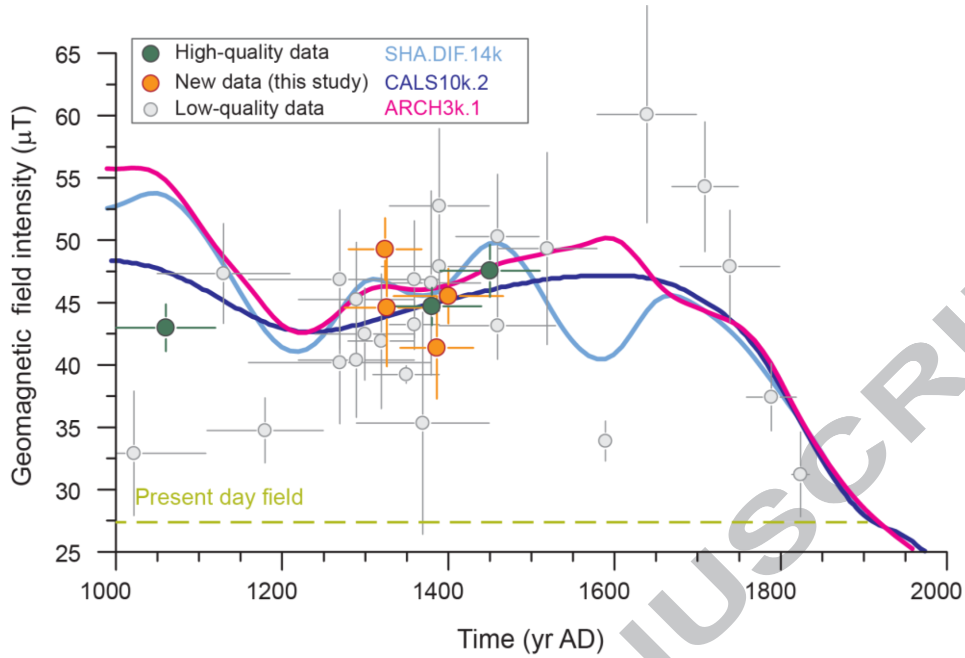

Figure 6. *Archeointensity data available for Argentina. Our new results are plotted in orange. Previous high-quality data are shown in green and data that do not fulfill the quality criteria detailed in the text are plotted as grey circles. Results are compared with predictions obtained from three different time-varying global geomagnetic field models: ARCH3k.1 (Korte et al., 2009), SHA.DIF.14k (Pavón-Carrasco et al., 2014a) and CALS10k.2 (Constable et al., 2016). Archeointensity values and model predictions are referred to Pueblo Viejo de Tucute coordinates (23.03º S, 66.08º W).*

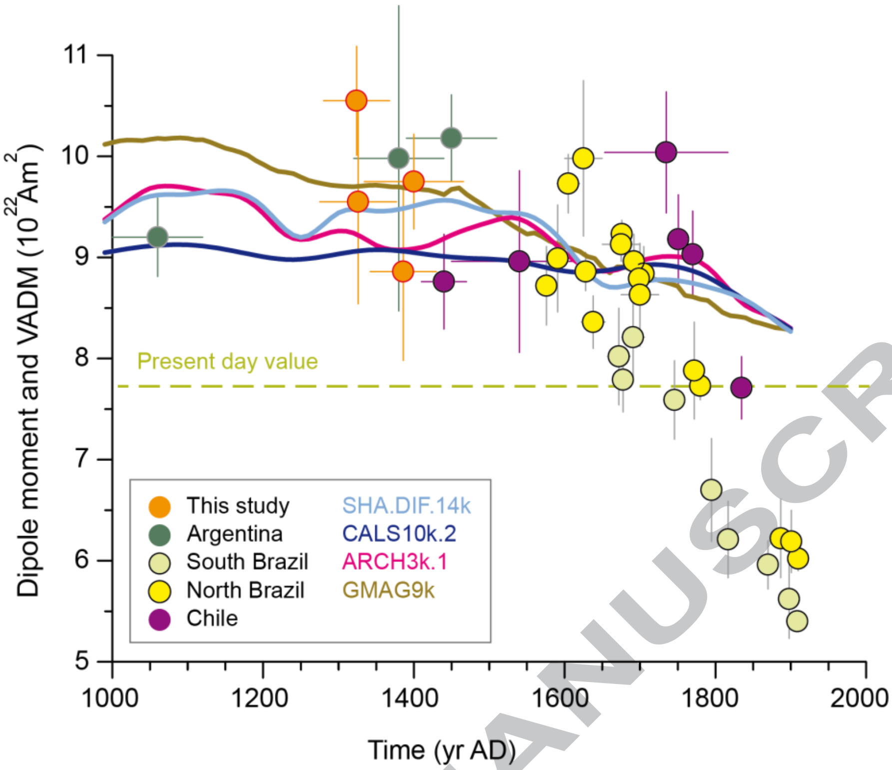

Figure 7. *High-quality VADM values available for South America for the last 1000 years and comparison with different global dipole moment reconstructions (see text for furthers details).*

Site	Lab. code	Lat. (S)	Long. (W)	^{14}C sample	^{14}C date (yr BP)	Calibrated age at 95.4 % (ys AD)	Final ascribed age (yr AD ± sd)	N	n	$F_m \pm sd$ (µT)	σ_b/F_m (%)	VADM 10^{22} Am^2
Pueblo Viejo de Potrero	POPI	22.95º	66.06º	LP-2020	460 ± 90	[1305, 1642]	1400 ± 66	7	15	45.5 ± 2.2	4.8	9.8
				AA1000155	557 ± 46	[1299, 1437]						
Calaverioj	CASU	23.03º	66.06º	LuS-6735	530 ± 50	[1301, 1449]	1386 ± 44	8	13	41.4 ± 4.1	9.9	8.9
Pueblo Viejo de Tucute	TUS2	23.03º	66.08º	LP-500	680 ± 50	[1257, 1400]	1324 ± 44	6	14	49.3 ± 2.5	5.1	10.6
Pueblo Viejo de Tucute	TUCI	23.03º	66.08º	LP-1480	670 ± 70	[1224, 1413]	1326 ± 51	10	17	44.6 ± 4.7	10.5	9.5

Table 1. *Summary of the new archeointensities obtained for NW Argentina together with associated radiocarbon dates.*

Columns from left to right. Site, name of the archeological site where the samples were collected; Lab code, Laboratory code for the studied collection; Lat. and Long., geographical coordinates; ^{14}C sample and date, ^{14}C sample name and corresponding date in yr BP before *calibration; Calibrated age (AD), calibrated ^{14}C ages (AD); Final ascribed age (yrs AD), assigned age for each collection and associated standard deviation; N, number of independent fragments retained to calculate mean intensity; n, number of specimens retained to calculate mean intensity; Fm ± sd, mean intensity and standard deviation corrected for TRM anisotropy and cooling rate effect upon archeointensity estimates;* σ_b/F_m*, standard error/mean site field; VADM, values of the virtual axial dipole moment. The intensity values estimated at the specimen level together with the corresponding quality parameters are described in Table S1 (Supporting Information).*

Highlights:

- TRM anisotropy correction is an essential requirement in paleointensity studies
- Four new high-quality archeointensities are obtained for NW Argentina
- The decrease of geomagnetic field intensity started in South America after 1600 AD