ISSN: 2007-9656

LATINMAG LETTERS

October 2017 - Volume 7 - Number 7
LL17-0702Rs

RESEARCH PAPER

Published on behalf of the Latin American Association of Paleomagnetism and Geomagnetism by the Instituto de Geofisica, Universidad Nacional Autónoma de México.

Detailed early Holocene (10.3 cal kybp) paleomagnetic record with anomalous directions from Mendoza Province

H.G. Nami, C.A. Vásquez, V. A. Durán

17 pages, 10 figures, 2 tables

Latinmag Letters Volume 7, number 7 (2017), LL17-0702Rs, 1-17

RESEARCH PAPER

Published on behalf of Latin American Association of Paleomagnetism and Geomagnetism by the Instituto de Geofisica, Universidad Nacional Autónoma de México

Detailed early Holocene (10.3 cal kybp) paleomagnetic record with anomalous directions from Mendoza Province, Western Argentina

Hugo G. Nami[1 2], Carlos A. Vásquez[1, 3], Víctor A. Durán[4]

[1] CONICET-Universidad de Buenos Aires, Instituto de Geociencias Básicas, Aplicadas y Ambientales de Buenos Aires (IGEBA), Departmento de Cs. Geológicas, Facultad de Ciencias Exactas, Físicas y Naturales (UBA), Ciudad Universitaria, Pabellón II, Buenos Aires (C1428EHA), República Argentina.
[2] Associate researcher, Department of Anthropology, National Museum of Natural History, Smithsonian Institution, Wa. D.C., U.S.A.
[3] Ciclo Básico Común, Universidad de Buenos Aires, Ciudad Universitaria, Pabellón III, Buenos Aires (C1428EHA), República Argentina.
[4] Laboratorio de Geo-arqueología, CONICET-Facultad de Filosofía y Letras, Universidad Nacional de Cuyo, Mendoza, República Argentina.
* Corresponding e-mail: hgnami@fulbrightweb.org
Received: July 2017; Accepted: September 2017; Published: October 2017

Abstract. A detailed palaeomagnetic study was performed in Barrancas de Maipú archaeological locality, Mendoza province, western Argentina. The paleomagnetic research took into account rock magnetism and directional analysis. The former reveals that the main magnetic carrier was magnetite or Ti-poor titanomagnetite. Characteristic remanence magnetization directions were determined by progressive alternating field demagnetization. Data from 47 cores showed anomalous directions far from the present magnetic field during the early Holocene in a well dated section of ~10.3 calibrated radiocarbon kiloyears before present. The virtual geomagnetic poles were calculated from the directional results. When plotted in a present world map are concentrated over Australia and Southeast Asia. The anomalous directions at Barrancas de Maipú probably represents a possible geomagnetic field excursion occurred during the Pleistocene-Holocene transition and initial Holocene recorded in several sites and localities across the world.
Keywords: Paleomagnetism, geomagetic excursion, early Holocene, Archeology, South America, Argentina.

Resumen. Un estudio paleomagnético detallado se llevó a cabo en la localidad arqueológica de Barrancas de Maipú, provincia de Mendoza, oeste de Argentina. La investigación tuvo en cuenta magnetismo de rocas y análisis direccional. El primero reveló que los principales portadores fueron magnetita o titanomagnetita pobre en Ti. La magnetización remanente característica fue determinada por desmagnetización progresiva utilizando campos alternos. Los datos de 47 especímenes mostraron direcciones anómalas lejanas del campo magnético actual durante el Holoceno temprano en una sección bien datada en ~10.3 miles de años (kiloaños) radiocarbónicos calibrados antes del presente. Los polos geomagnéticos virtuales se calcularon a partir del resultado del análisis direccional. Graficados en un mapamundi se concentran sobre Australia y Sudeste de Asia. Las direcciones anómalas de Barrancas de Maipú probablemente representan a una posible excursión del campo magnético acaecida durante la transición Pleistoceno-Holoceno e inicios del Holoceno registrada en varios sitios y localidades alrededor del mundo.
Palabras clave: Paleomagnetismo, excursión geomagnética, Holoceno temprano, Arqueología, Sudamérica, Argentina.

1. Introduction

Current geomagnetic time scales postulate a continuous normal geomagnetic field (GMF) polarity for the last 780,000 years during the Brunhes Chron; however, it was affected by a few intervals when either briefly reversed or behaved anomalously (Cande and Kent, 1995). This fact indicates that this normal polarity has been interrupted by significant departures from the dipole field configuration (Tarling, 1983; Lund *et al*., 2001, 2006; Laj and Channel, 2007). These departures are considerably larger than those seen in secular variations observed during historical times, and sometimes even attain opposite polarity, originating GMF excursions. By definition, they are short intervals of anomalous field directions that occur within a broader period of 'stable' normal or reversed magnetic polarity (Verosub and Banerjee, 1977; Thouveny and Creer, 1992; Laj and Channell, 2007; Singer, 2014). Several records in different materials, times, and places suggest that geomagnetic events with anomalous behavior indicates that the geodynamo went to unstable states much more frequently in the Brunhes Chron (*e.g*. Nowaczyk *et al*., 1994; Nowaczyk and Knies, 2000; Marco, 2002; Lund *et al*., 2006; Jicha, *et al*. 2011). In more recent times, particularly since the Pleistocene-Holocene transition and Holocene, during the last ~11000-9000 uncalibrated, or ~13000-11000 calibrated years before present (hereafter, respectively referred as ~11-9 kybp or ~13-11 cal kybp), it is accepted that the GMF has been normal as it is now (*e.g.* Creer, 1985; Sinito and Nuñez, 1997; Gogorza *et al*., 2000; 2012; Korte and Constable, 2005a, 2005b; among others). Nevertheless, a growing number of late Pleistocene and Holocene paleomagnetic records are suggesting that the GMF was affected by an anomalous behavior. This sort of recent GMF characteristic have been recorded in diverse parts of the Earth (*e.g*. Creer *et al*., 1976; Mörner, 1977; Burakov and Nachasova, 1990; Bakhmutov, 1997; Chaparro *et al*., 2008; Dergachev *et al*., 2004, 2012; Geiss and Banerjee, 2003; Guskova *et al*., 2008; Kochegura and Pisarevsky, 1994; Lund *et al*., 2007, 2008; Nami, 1999a, 1999b, 2012; 2015; Nami *et al*., 2016; Nelson, 2009; Petrova and Pospelova, 1990; Platzman *et al*., 2010; Raspopov *et al*., 2003; Zhu *et al*., 1998; among others). Particularly, in Argentina and Chile it was reported in several places (Nami, 1995, 1999a, 2012, Nami and Sinito, 1993; Sinito *et al*., 1997, among others). Therefore, a research program aimed to know the GMF behavior in the southern cone of South America from diverse archaeological, paleontological and geological sections is being carried out (*e.g*. Nami 2006, 2011, 2012). In pursuit of this goal, a sampling was performed at Barranca de Maipú archaeological locality (BM, 33º 07′ 35.5" S, 68º 41′ 30.4" W) in Mendoza province, western Argentina (Fig. 1). As result of this investigation, paleomagnetic data obtained in the lower portion of a deep sedimentary pile from BM is reported.

2. Sampling site and chronology.

Located at the lowland of the southern Andes, BM is characterized by a landscape showing numerous ravines of varied depths (Fig. 2a). The geo-archaeological study reported by Moreiras and colleagues (2013) allowed knowing its geomorphological evolution occurring since late Pleistocene to very recent times (Fig. 3). In one of the principal zones of erosional gullies (33° 7' 36" S, 68° 41' 29" W), the exposures records the deposition occurred during the whole Holocene suggesting a relatively rapid and stable sedimentation (Moreiras *et al*., 2013). In a BM sediment pile of ~15 m depth, a thick sequence of intercalated layers of fine silt and sand indicates the existence of a humid microenvironment fed by freshets from the Andes during the Late Pleistocene-Early Holocene and a lagoon environment during most of the Holocene (Fig. 2b-c, 3).

At BM there have been an active erosive process since the last millennium, when the area became increasingly arid. As a part of this process a varied archaeological record was uncovered through the years. The area is then characterized, by numerous remains witnessing human occupations occurred through the

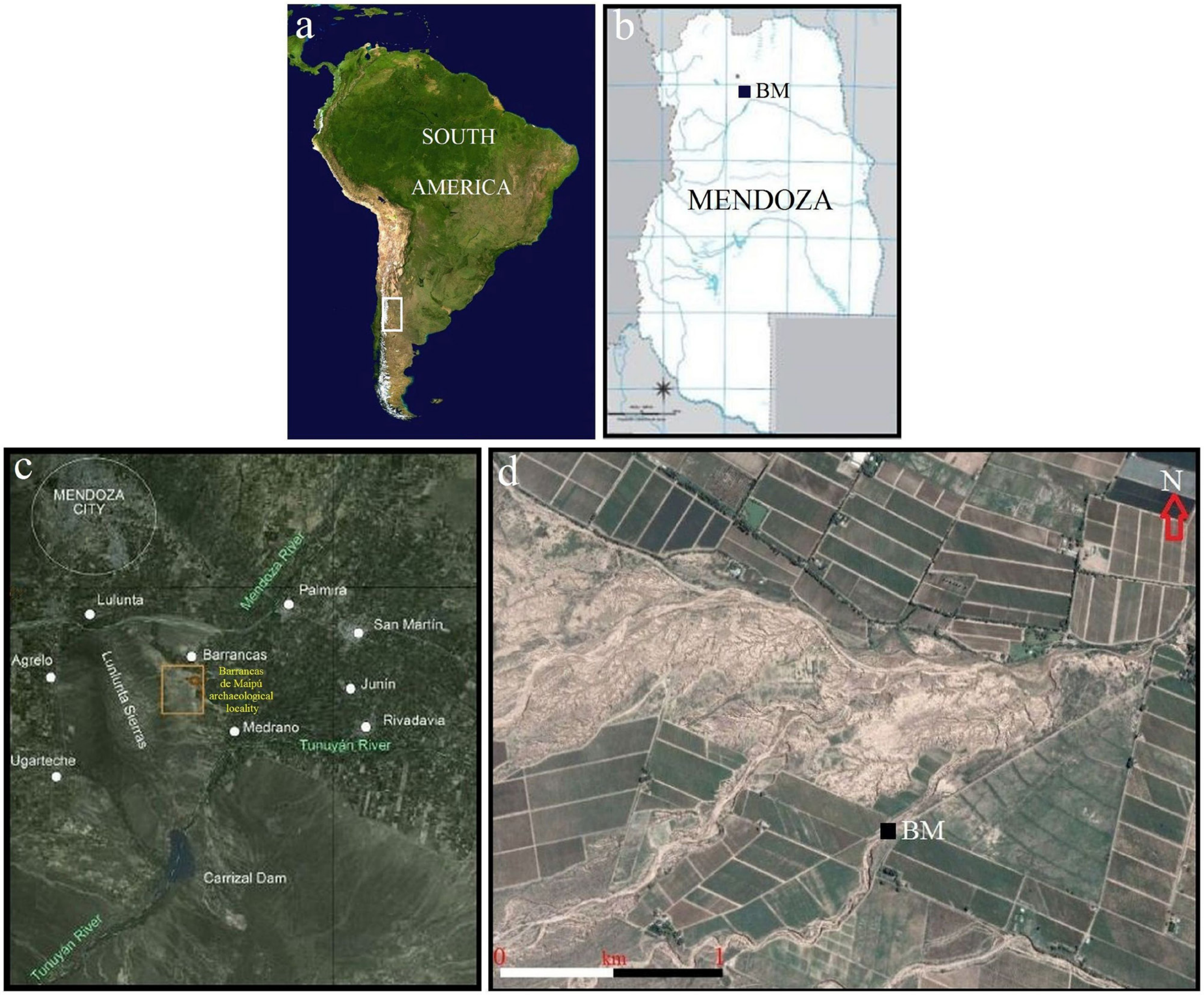

Figure 1. Map of South America (a) showing the location of the Mendoza province (b) Barrancas de Maipú: BM archaeological locality (b) and paleomagnetic sampling site (c-d).

Holocene (Moreiras *et al*., 2013; Marsh *et al*., 2013). Interestingly, hearths are visible at different depths along the ravines' banks. At the bottom of one of the main ravines, 11.0 m depth below the surface, it was found a feature resembling a hearth that includes very dense concentrations of carbonized organic material and ash. Its size and shape suggest a bowl shaped hearth ~70 cm wide and 10 cm deep at its center (Fig. 3d). There, the fine sand and clay suggest a lagoon environment (Moreiras *et al*., 2013). A charcoal sample obtained from this feature, was processed by the *Carbon-14 Laboratory* of La Plata University, Argentina. The sample yielded a single conventional radiocarbon uncalibrated age of 9180 ±120 years BP (LP-2771) or 10300 calibrated years BP (Moreiras *et al*., 2013). For the purpose of this paper, the two-sigma calibrated ranges date (10151-10700 years BP) was calculated using the "Calib radiocarbon calibration program" (Stuiver and Reimer, 1993) and the calibration data set assembled by Reimer and colleagues (2013).

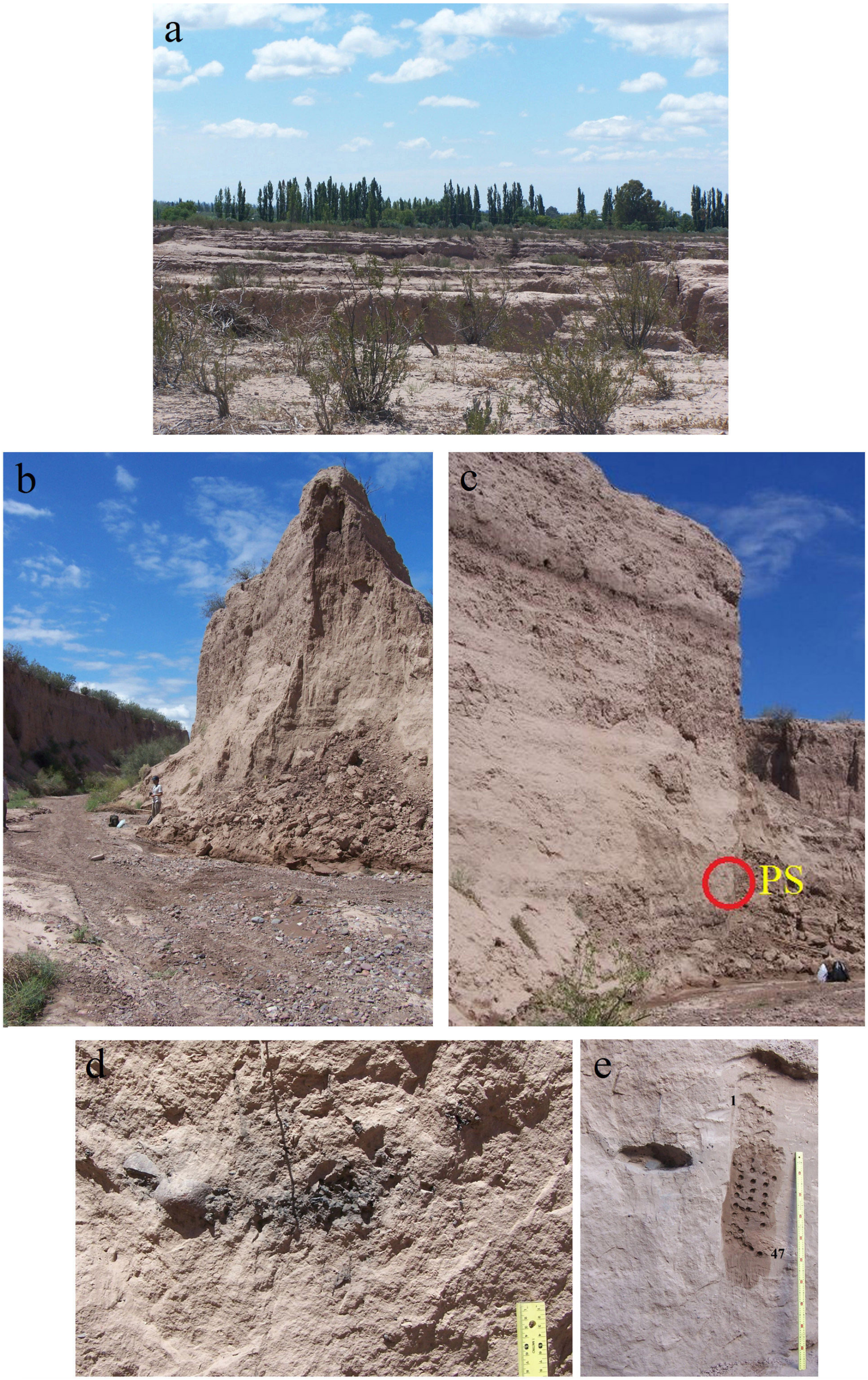

Figure 2. General view of Barrancas de Maipú locality (a), and ravine where the paleomagnetic sampling (PS) was performed (b-c) denoted with a circle in c). The dated combustion feature (d) and detail of the paleomagnetic sampling located at its right after removing the samples (e).

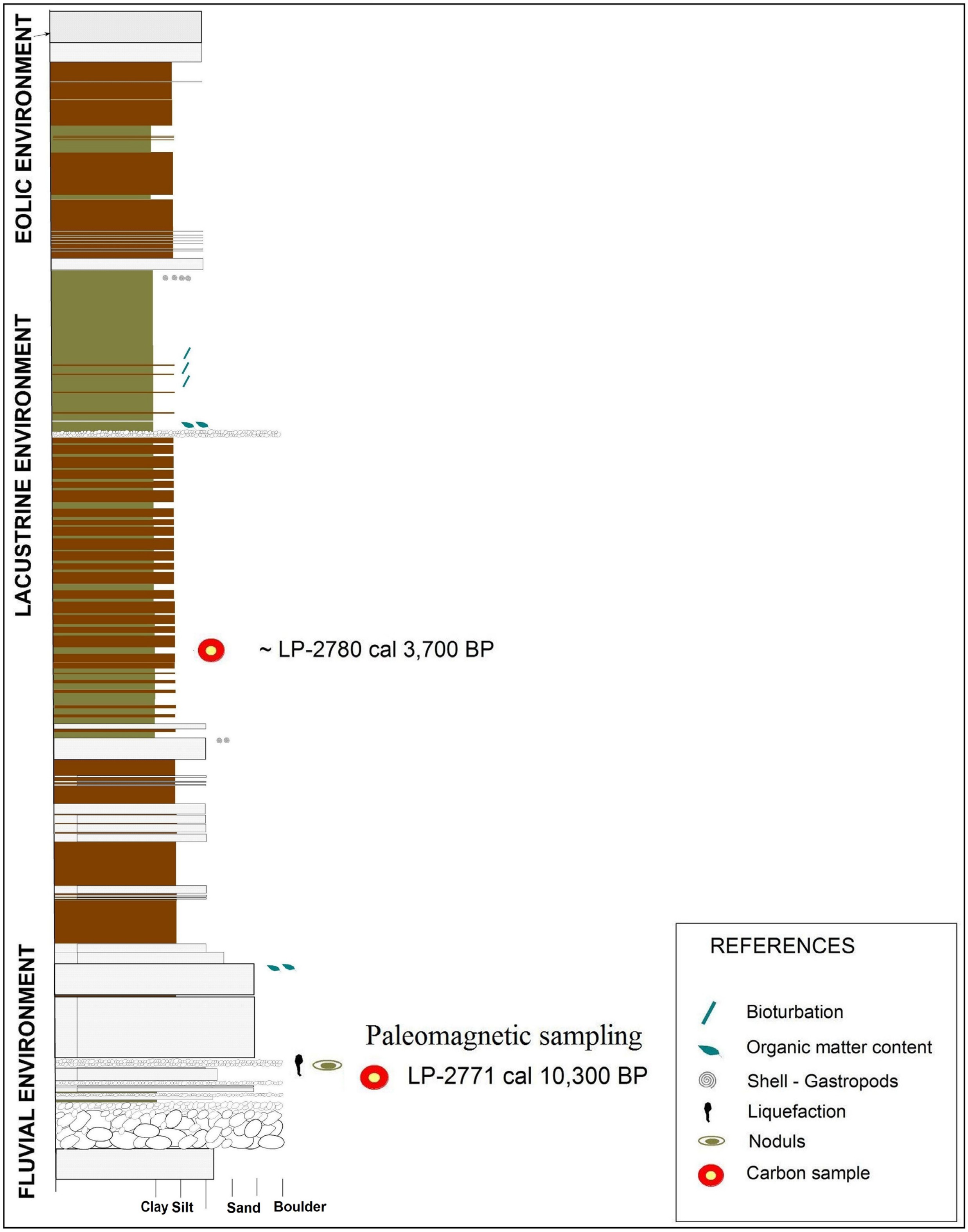

Figure 3. Stratigraphic section of BM (modified after Moreiras *et al*. 2013).

3. Paleomagnetic sampling, analysis and results

As showed in Figure 2e, sampling was done on a vertical way next to the dated hearth at ~20 cm to the right. The collection of samples was made using cylindrical plastic containers 2 cm diameter and 2 cm long, carefully pushing into them the sediments with the precaution that they overlapped about 50%. Their orientation was measured using a Brunton compass. Sample sediments were consolidated with sodium silicate once removed and finally, were numerated from the top to the bottom.

The analysis of the sampling was performed at the "Laboratory of Paleomagnetism Daniel A. Valencio", Buenos Aires University. In order to characterize the magnetic mineralogy, the variation of susceptibility (k) with temperature and field amplitude was performed after directional analysis in samples BM5, BM23 and BM42. The measurements were carried out with a Kappabride AGICO model MFK1-FA, frequency was setting to 976 Hz, the heating and cooling curves were acquired between room temperature and 680° C. The field amplitude ranged between 30 A/m and 700 A/m. The thermomagnetic curves are shown in Figure 4, they exhibit very similar behavior that can be due to Ti-poor titanomagnetite (Kontny and de Wall, 2000) with a Curie temperature of near 585° C, which is near the Curie temperature of magnetite (Petrovský and Kapička, 2006). In Figure 5 are shown the variation of susceptibility with the field amplitude, between 20 A/m and 700 A/m. The index Vm, that characterizes the maximum susceptibility variation with field, being defined as follows: Vm = 100(kmax − kmin)/kmin, ranged between 2.8 % and 2.21 % for the three samples, it is compatible with magnetite or Ti-poor titanomagnetite (Hrouda, 2009). Therefore, the main magnetic carriers in the analyzed sediments are magnetite and Ti-poor titanomagnetite.

All samples for directional analysis were subjected to progressive alternating fields (AF) demagnetization in steps of 3, 6, 9, 12, 15, 20, 25,

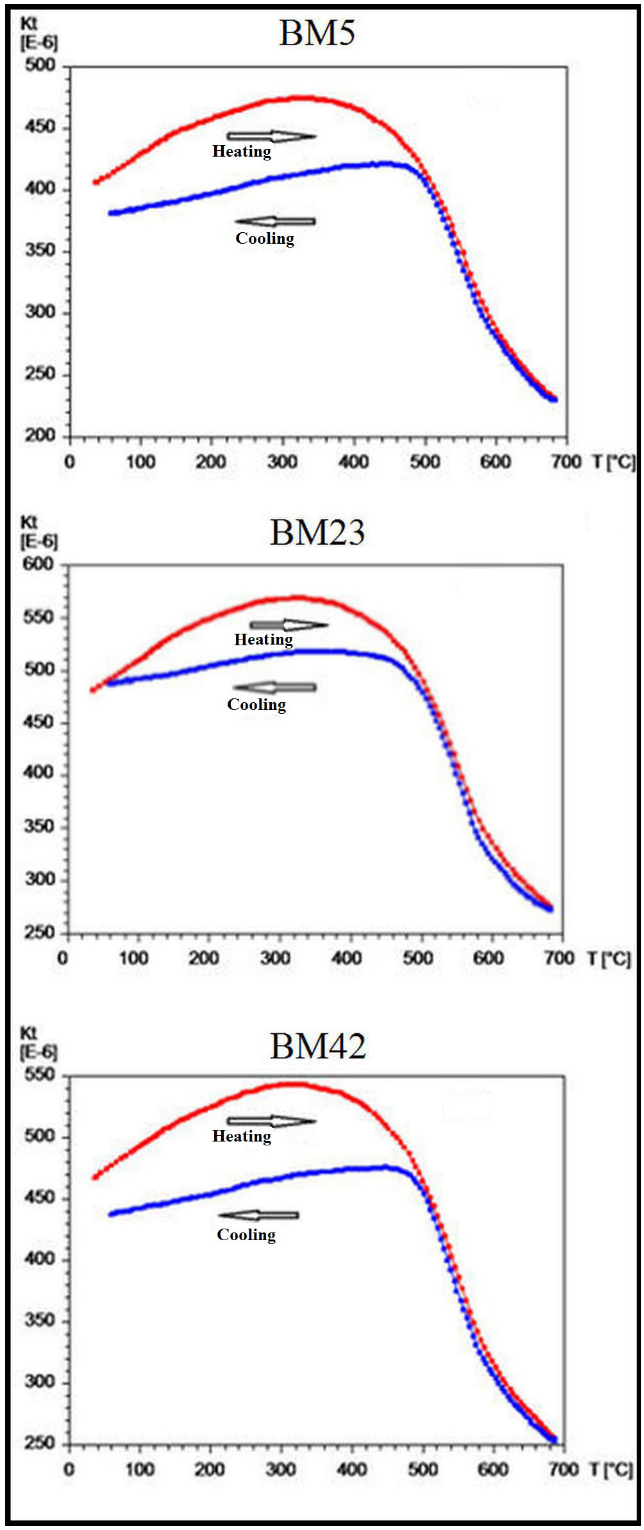

Figure 4. Thermomagnetic curves for samples BM5, BM23 and BM42. The heating curves of the three samples show a "hump" observable in the range ~200ºC and 500ºC, which may be attributed to titanomagnetites.

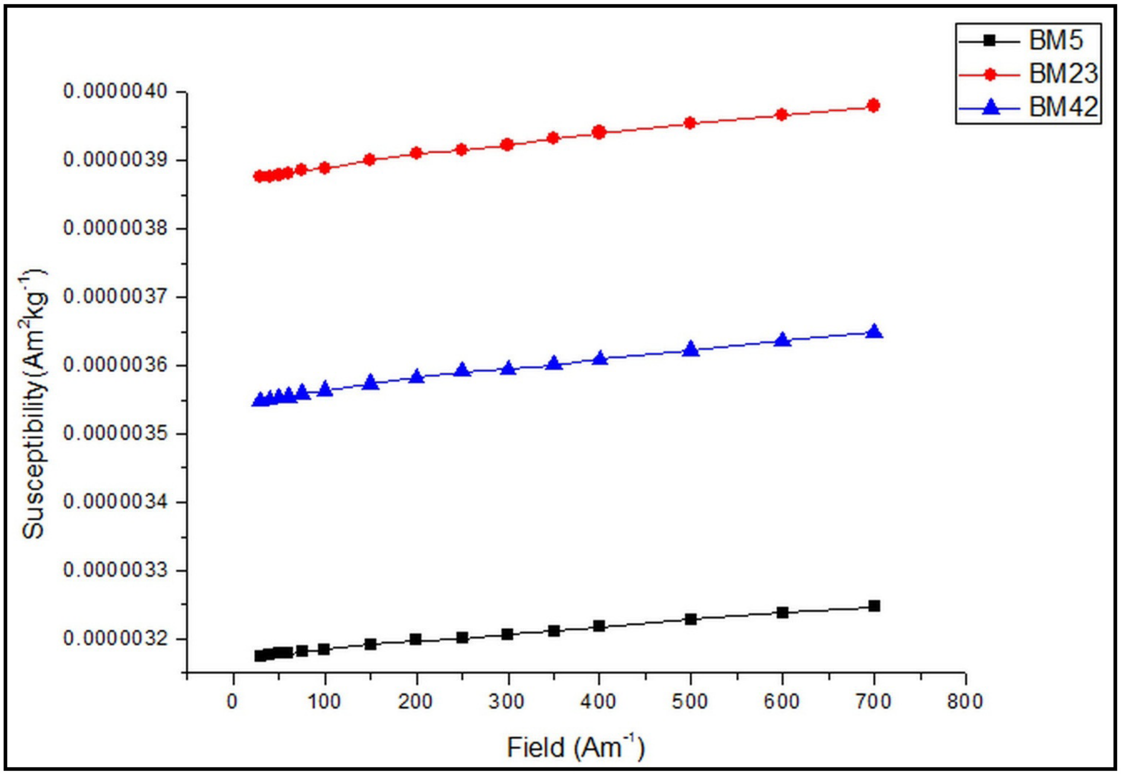

Figure 5. Variation of initial susceptibility with the amplitude of the applied field. The curves show a slightly increasing with the field, which can be attributed to Ti- poor titanomagnetites.

30, 40 and 60 mT in a 3-axis static degausser, attached to a 2G cryogenic magnetometer and subsequently measured with the apparatus. Additional steps of 80, 100 and 120 mT were used in some cores. Characteristic remanent magnetization (ChRM) was calculated using principal components' analysis (Kirschvink, 1980). Paleomagnetic data were processed with the "Interactive analysis of palaeomagnetic data" (Torsvik, 1992) and MAG88 (Oviedo, 1989) computer programs. All samples display a common "highly reliable" pattern with practically univectorial behavior decaying towards the origin (Fig. 6). Most of them yielded vector projection diagrams (VPD) with one magnetic component. In the majority, a ChRM could be defined trending towards the origin in the Zijderveld (1967) diagrams. A few samples showed a soft viscous secondary magnetic component easily removed at 3 mT (*i.e*. BM20, Fig. 4d). In the majority of the cores, less than about 90% of the NRM was removed at 60 mT (BM2, BM5, BM7, BM33, Fig. 6a, e); However 100 and 120 mT were used in some specimens (BM10, BM13, BM20, BM47, Fig. 6b, f). A few specimens exhibited residual directions not erased at demagnetization fields of 120 mT, causing some deviation away from the origin. Nevertheless, they do not affect the isolated ChRM (*e.g*. BM20; Fig. 6d). Maximum angular deviations were generally within low values and most of them ranges between 0° to 5° (n = 43, 91.5 %) and 5.1° to 10° (n = 4, 8.5%).

The number and intervals of demagnetization steps used to isolate the ChRM of each site are depicted in table 1. Surprisingly, the totality of the cores yielded strongly similar anomalous directions far from the present GMF (IGRF: D = -0.979°, I = -33.444°) for 2012, year when the sampling was performed. The magnetogram of the declination and inclination profile is showed in Figure 7. Both are stable logs with declination swings between ~180° to 270°, and negative inclination values ranging from ~-30° to -70°.

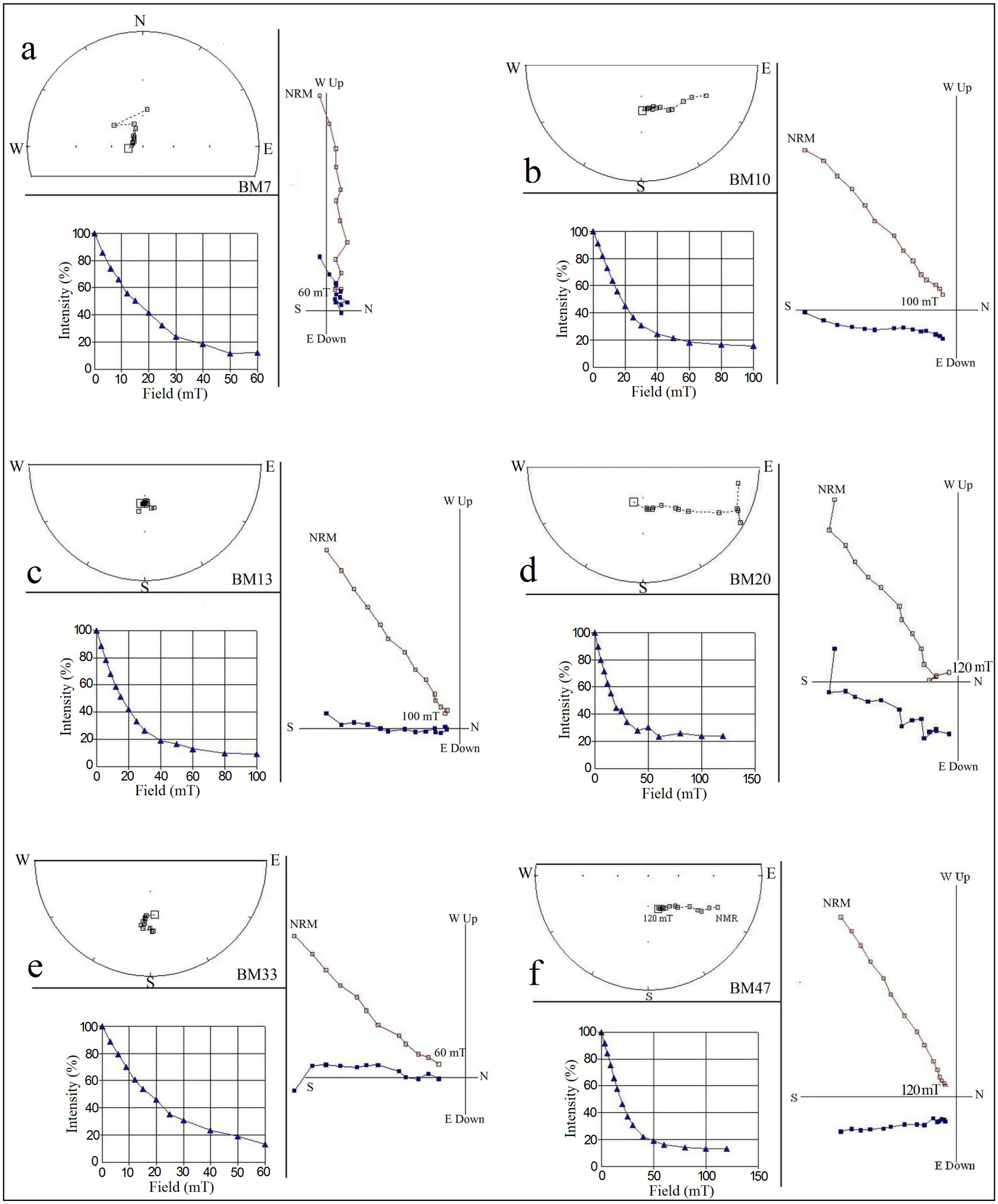

Figure 6. Demagnetization behavior for six specimens from BM site, showing the stereographic projections and normalized magnetization (left), and orthogonal vector diagrams (right). In each case the specimens were demagnetized with alternating fields.

Table 1. Characteristic remanent magnetization, virtual geomagnetic pole positions, and intervals of each sample. Negatives values show negative inclination or VGP located in the Southern Hemisphere.

Sample	D°	I°	VGP		Interval of ChRM
			Long. E	Lat.	
1	205	-62	130	-10	0.Or.
2	213	-48	142	-20	3-Or.
3	213	-58	137	-12	3-50
4	189	61	119	-14	3-60
5	199	-49	130	-24	3-Or.
6	206	-42	138	-27	3-120
7	256	-79	135	-26	3-40
8	210	-49	139	-21	3-Or.
9	195	-54	125	-21	0-Or.
10	187	-48	119	-27	0-100
11	184	-48	116	-27	0-80
12	185	-46	117	-29	3-Or.
13	185	-53	116	-23	3-Or.
14	200	-56	128	-18	3-80
15	223	-47	150	-16	3-Or.
16	181	-54	113	-22	3-Or.
17	218	-38	151	-24	3-Or.
18	210	-64	132	-6	3-Or.
19	242	-62	152	5	3-Or.
20	203	-52	132	-20	3-120
21	196	-50	127	-24	3-Or.
22	208	-31	144	-23	3-50
23	278	-50	179	23	40-Or.
24	241	-53	159	-2	3-Or.
25	218	-50	145	-16	3-Or.
26	190	-50	121	-25	0-Or.
27	194	-51	125	-23	3-Or.
28	211	-71	129	3	0-Or.
29	214	-35	148	-28	0-Or.
30	190	-36	123	-36	3-Or.
31	220	-53	145	-13	3-60
32	203	-47	134	-25	0-Or.
33	186	-39	118	-34	3-Or.
34	200	-62	126	-11	3-Or.
35	214	-44	145	-22	3-Or.
36	198	-67	123	-5	3-Or.
37	204	-46	135	-25	3-Or.
38	205	-52	134	-20	3-Or.
39	214	-42	146	-24	3-60
40	223	-57	145	-9	2-20
41	186	-51	117	-25	0-Or.
42	240	-64	149	6	0-Or.
43	212	-53	139	-17	0-60
44	183	-29	116	-41	0.80
45	203	-44	135	-27	3-40
46	185	-58	116	-18	0-Or.
47	170	-58	104	-17	0-Or.

Intervals of selected ChRM are given in mT. References: D: Declination, I: Inclination, Long.: Longitude, Lat.: Latitude, Int.ChRM: Intervals of selected ChRM, Or.: Origin in the Zijderveld diagram.

Figures 8 and 9 respectively depict the stereoplot directional data and virtual geomagnetic pole (VGP) positions calculated from BM samples. When plotted in a present world map, VGPs are very well clustered in Australia and New Guinea (Fig. 10).

4. Discussion and conclusion

Detailed paleomagnetic research performed in the BM site yielded a record with anomalous directions during the early Holocene at ~9.2 kybp or 10.1-10.7 cal kybp. It shows a difference of ~140°-180° in declination and ~30°-50° in inclination from the calculated IGRF. Anomalous paleomagnetic records may be for a number of reasons. Indeed, various causes can give rise to the measurements of anomalous directions of remanent magnetism which does not reflect the true GMF behavior, such as diverse deposition processes, chemical alterations, as well as sedimentary physical disturbances (Verosub and Banerjee, 1977; Langereis *et al*., 1992). The anomalous directions may also reflect true GMF excursions, which are defined when VGPs differ by more than 45° from the geographic pole during normal or reverse polarity, signifying

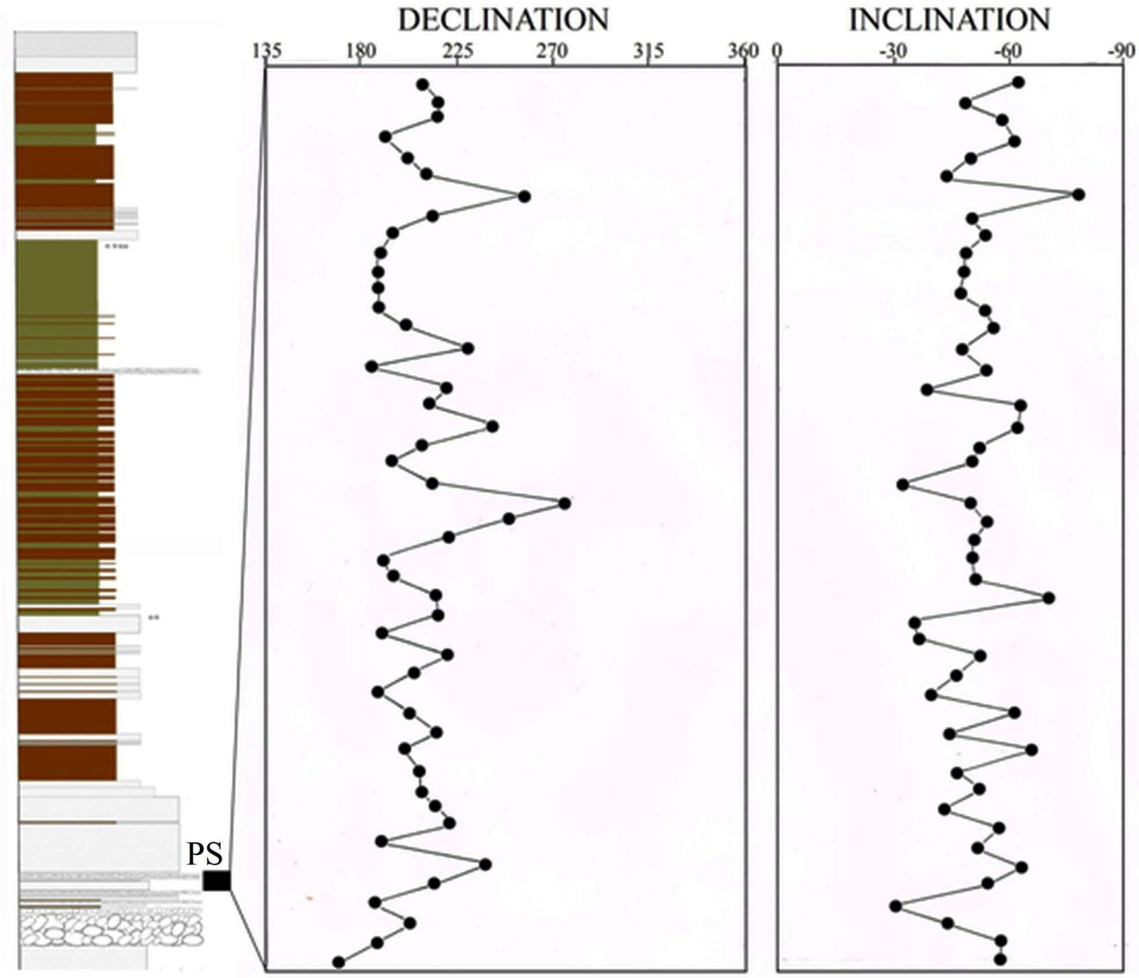

Figure 7. Plots of vertical distribution of the declination and inclination of each sample from BM related with the paleomagnetic sampling (PS) location denoted with a black rectangle in the stratigraphic section.

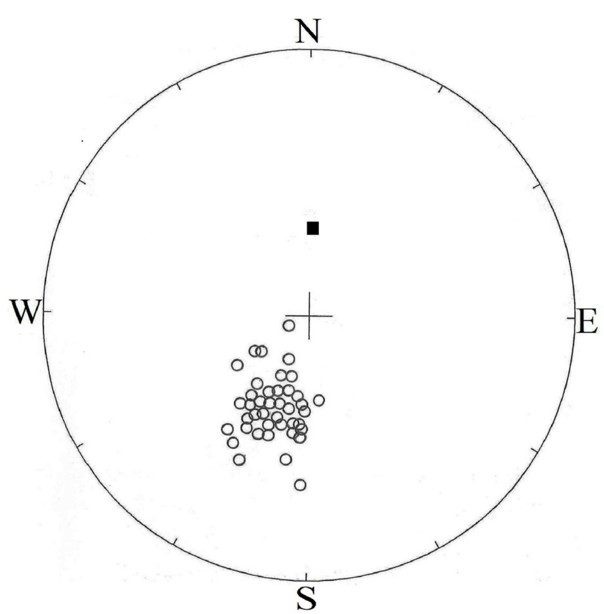

Figure 8. Stereoplot of directional data with field correction from BM. Solid and open circles respectively represent positive and negative values. The IGRF direction is indicated with a black square.

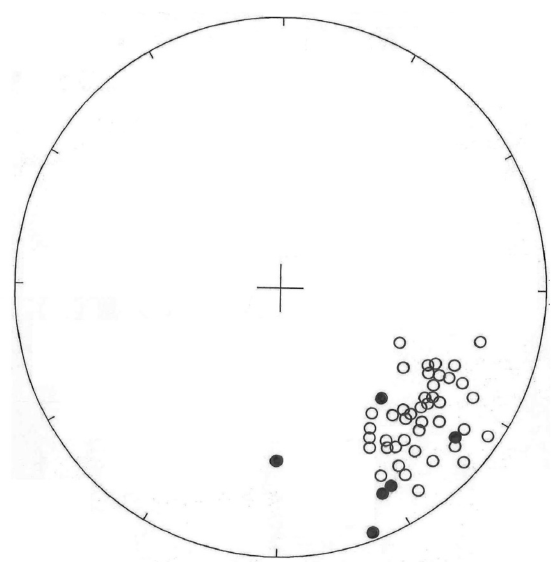

Figure 9. Stereographic projection of VGPs calculated from directions of ChRM from BM site. Solid circles show those ones located in the Northern Hemisphere. The center of the projection is the geographic Southern Pole.

that they may be considered a major deviation in GMF behavior (Verosub and Banerjee, 1977; Merrill and McFadden, 2005; Laj and Channel, 2007). Hence, if the anomalous direction observed at BM is not a result of a sedimentary artifact and/or perturbations, it may represent the record of the likely GMF excursion occurred in the southern cone of South America during the late Pleistocene/early Holocene (Nami, 1995, 1999a, 2012). Virtual geomagnetic pole positions are located on or close by to Oceania; this situation was previously observed in sites with anomalous directions in the southern cone during the Pleistocene/Holocene transition, Early, Middle and Late Holocene (Nami, 1995, 1999a, 2012, 2015). VGPs patchs with similar positions have been recorded in other transitional records from different epochs and periods of Earth´s history (*e.g*. Creer and Ispir, 1970: Fig. 7-8; Laj *et al*., 2006: Fig. 7; Hoffman and Singer, 2004: Fig. 1; Hoffman *et al*., 2008; Fig. 8).

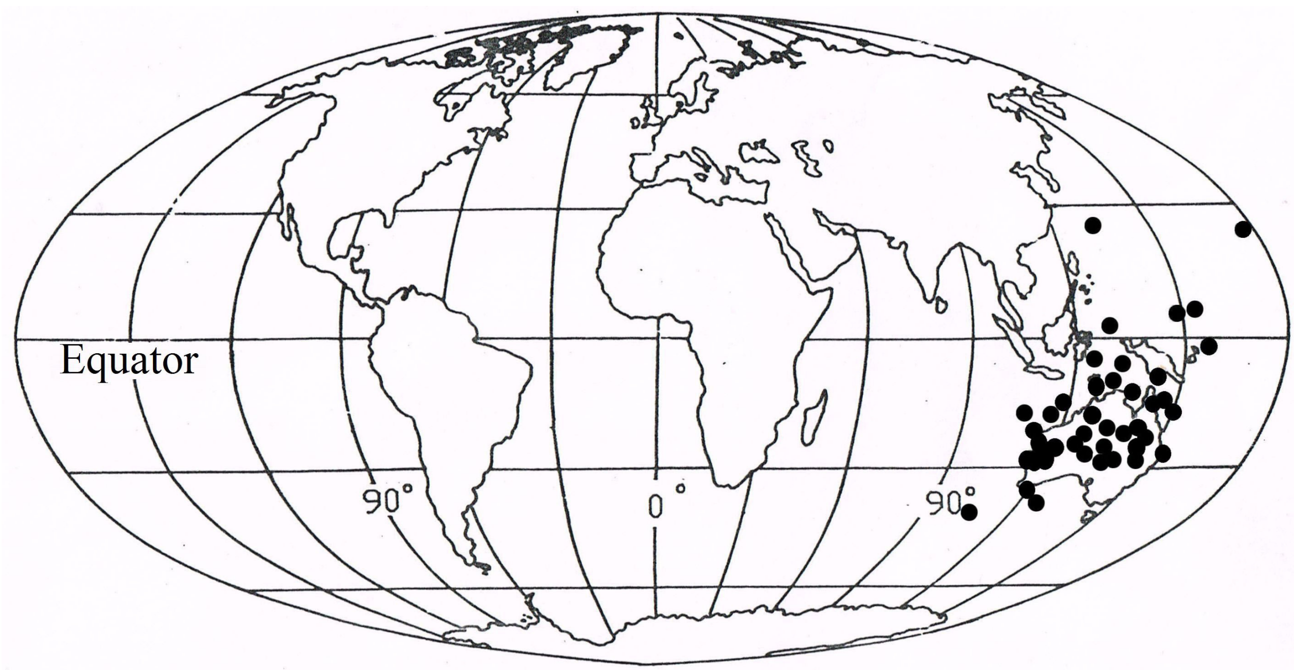

Figure 10. World map showing the location of the VGP obtained from BM.

According to well dated records from other parts of the Earth, this kind of possible anomalous GMF behavior occurred during the Pleistocene-Holocene transition and initial Holocene at ~10.5 and 9.2 kybp. In fact, other anomalous directions with large departures of the GMF were recorded in several sites and localities across the world. They belong from marine (Lund *et al*., 2008; Nelson *et al*., 2009), lacustrine (Mörner, 1977; Geiss and Banerjee, 2003; Chaparro *et al*., 2008), and continental (Nami, 1999a, 2012, 2015) deposits. The uncalibrated available dates from most of those sites have been unified using the "Calib radiocarbon calibration program" mentioned above (Table 2). In North America, the Grandfather Lake in Alaska, yielded records with an excursion dated at the initial Holocene between ~11.1-11.7 cal kybp (Geiss and Banerjee, 2003). Furthermore, similar directions were recorded in Argentina at Alero de las Circunferencias (10.6-11.1 cal kybp), and Las Buitreras cave (Nami, 1999a). These anomalous directions might occurr at a similar time to those excursions observed by Lund and associates (2008) in marine sediments of the Tahiti Coral Reef

(South Pacific Ocean) dated at 10.6 and 11.1 cal kybp. In the same region another excursion was dated at 12.5 cal kybp (Lund *et al*., 2007) which was attributed to the one registered in West Coast South Island, New Zealand (Nelson *et al*., 2009). In South America, at El Tingo in Ecuador, two stable oblique reverse records with a large fluctuation far from the present GMF recorded at ~10.5 kybp or 12.2 cal kybp (Nami, 2015). Mylodon cave in Southern Chile yielded a stable record with intermediate and reverse directions registered at sediments consistently dated at ~11.0-10.0 and ~5.0 kybp (Nami, 1995). In North America Creer and colleagues (1976) observed large GMF fluctuations at the Erieau Lake (Canada); also, in Mexico at La Hoya de Nicolas maar lake, an anomaly interpreted as a geomagnetic excursion or even a very short reversal of the GMF has been reported (Chaparro *et al*., 2008: 470). According to the age model developed by Chaparro and colleagues (2008) this anomaly lasted 800 years between 9060 and 9810 cal yr BP. Despite that the inclinations has the expected positive values during the time span under consideration, a number of paleosecular variation records in the northern Hemisphere, large amplitude swings in declination were recorded in Scandinavia and northern Russia (Bakhmutov, 1997; Backmutov *et al*., 1994; Saarnisto and Sarinen, 2001). A similar fact was also registered in southernmost Patagonia at Potrok Aike lagoon; there the PSV record yielded logs of negative inclination values with large amplitude variations in declination during the early Holocene at ~7-9 kybp (Gogorza *et al*., 2012)

Table 2. List of well dated records with anomalous GMF directions occurred during the last millennium of the Pleistocene and Pleistocene-Holocene transition.

Site	Environment	Dated Material	Uncalibrated AMS date yr BP	Calibrated age yr BP	Relative area under distribution	Reference
El Tingo	Continental	Sediment	10550± 55	12254-12256	0.001	Nami, 2015
Grandfather Lake	Lacustrine	Wood	9797±60	11100- 11331	1.00	Gneiss and Banerjee, 2003
Tahiti Coral Reef (younger excursion)	Marine	†	†	11600-11100	†	Lund *et al*., 2008
Alero de las Circunferencias	Continental	Charcoal	9180 ± 230	10918-11089	0.05	Nami, 1999a
‟	‟	‟	9190 ± 110	10612-10660	0.02	‟
Barrancas de Maipú	Continental	Charcoal	9180 ± 120	10151-10700	0.99	This paper

References: †: not given. To unify the results, all the available dates were calibrated using the "Calib radiocarbon calibration program" (Stuiver and Reimer, 1993) and the calibration data set assembled by Reimer and colleagues (2013). Calibrated ages are reported with 95.4 % (2 sigma) cal age ranges.

Well dated excursions may be used as chronological tools for dating (Parkes, 1986; Herz and Garrison, 1998; Merrill and McFadden, 2005). Hence, if the anomalous GMF behavior observed at ~9.2 kybp represents a true excursion, it will become an excellent magnetostratigraphic marker for the early Holocene in western Argentina. More research including the additional sampling and dating is needed in order to, confirm or reject the results provided above.

Acknowledgements

We are deeply indebted to: R. Barberena for his invaluable help during the fieldwork; the University of Buenos Aires and CONICET for their continuous support to the paleomagnetic investigations; the Laboratorio de Geo-arqueología, Facultad de Filosofía y Letras, Universidad Nacional de Cuyo for the logistic support; and the anonymous reviewers for their useful comments and suggestions.

References

Bakhmutov, V., 1997, Secular variations of the geomagnetic field, indicated in Early Holocene deposits of Lake Ladoga. *Geophys. J. 16*, 481–498.

Bakhmutov, V., Yevzerov, V., Kolka, V., 1994, Geomagnetic secular variations of high-latitude glaciomarine sediments: data from the Kola Peninsula, northwestern Russia. *Phys. Eart. Planet. Inter. 85*, 143-153.

Burakov, K. S., Nachasova, I. E., 1990, Anomalous Behaviour of the Geomagnetic Field in the 1st thousand Years B.P. Geomagnetic Field in Quaternary. Zipe 62, 135-138, Akademie der Wissenschaften der DDR, Postdam.

Cande, S.C., Kent, D.V. 1995, Revised calibration of the geomagnetic polarity timescale for the late Cretaceous and Cenozoic. J*. Geophys. Res, 100*, 6,093-6,095.

Chaparro, M. A. E. , Böhnel, H. N., Byrne, R., Nowaczyk, N. R., Molina-Garza, R. S., Parkand Jörg J., Negendank, F. W., 2008, Palaeomagnetic secular variation and rock-magnetic studies of Holocene sediments from a maar lake (Hoya de San Nicolas) in Central Mexico. *Geophys. J. Int. 175(2)*, 462-476. doi: 10.1111/j.1365-246X.2008.03893.x

Creer, K.M., 1985, Review of lake sediment palaeomagnetic data. *Geophys. Surv*. 7, 125-160.

Creer, K. M., Ispir, Y., 1970, An interpretation of the behavior of the geomagnetic field during polarity transition. *Phys. Earth Planet. Inter. 2*, 283.

Creer, K. M., Anderson, T. W., Lewis, C.F.M., 1976, Late Quaternary geomagnetic stratigraphy recorded in the Lake Erieu sediments. Earth Planet. Sc. Lett., 31, 37-49.

Dergachev, V. A., Raspopov, O. M,, van Geel, B., Zaitseva G. I., 2004, The ´Sterno-Etrussia´ Geoamagnetic Excursion around 2700 BP and Changes of Solar Activity, Cosmic Ray Intensity, and Climate. Radiocarbon, 46, 661-681.

Dergachev, V. A., Vasiliev, S. S., Raspopov, O. M., 2012, Climate Variations and the Shift of the Geomagnetic Poles of the Earth. In: Proceedings of the 9th Intl Conf. “Problems of Geocosmos”, Saint-Petersburg State University, St. Petersburg, pp. 33-38.

Geiss, C. E., Banerjee, S. K., 2003, A Holocene–Late Pleistocene geomagnetic inclination record from Grandfather Lake, SW Alaska. *Geophys. J. Int. 153*, 497–507

Gogorza, C.S.G., Sinito, A.M., Vilas, J.F., Creer, K., Nuñez, H., 2000, Geomagnetic Secular Variations. Over the Last 6500 Years as Recorded by Sediments from the Lakes of South Argentina. *Geophys. J. Int. 143*, 787–798.

Gogorza, C. S. G., Irurzun, M. A., Sinito, A. M., Lisé-Pronovost, A., St-Onge, G., Haberzettl, T., Ohlendorf, C., Kastner, S., Zolitschka, B., 2012, High-resolution paleomagnetic records from Laguna Potrok Aike (Patagonia, Argentina) for the last 16,000 years. Geochem. Geophys. Geosyst., 13, Q12Z37, doi:10.1029/2011GC003900.

Guskova, E.G., Raspopov, O.M., Piskarev, A.L., Dergachev, V., A. 2008, Magnetism and Paleomagnetism of the Russian Arctic Marine Sediments. In: Proceedings of the 7th Intl Conf. “Problems of Geocosmos”, Saint-Petersburg State University, St. Petersburg, pp. 380-385.

Herz, N., Garrison, E. G., 1998, Geological Methods for Archaeology. Oxford University Press, New York.

Hoffman, K.A., Singer, B.S., 2004, Regionally recurrent paleomagnetic transition fields and mantle processes. In: Channell, J.E.T., Kent, D.V., Lowrie, W., Meert, JgG. (Eds.), Timescales of the Paleomagnetic Field. *AGU, Geophysical Monograph, 145*. American Geophysical Union, Washington, DC, pp. 233–243.

Hoffman, K.A., Singer, B.S., Camps, P., Hansen, L.N., Johnson, K., Clipperton, S., Carvallo, C., 2008, Stability of mantle control over dynamo flux since the mid-Cenozoic. *Phys. Earth Planet. Int. 169*, 20-27.

Hrouda, F., 2009, Determination of field-independent and field-dependent components of anisotropy of susceptibility through standard AMS measurement in variable low fields I: Theory. *Tectonophys. 466(1–2)*, 114–122, doi:10.1016/j.tecto.2008.05.026.

Jicha, B. R., Kristjánsson, L., Brown, M. C., Singer, B. S., Beard, B. L., Clark, J. M., 2011, New age for the Skálamælifell excursion and identification of a global geomagnetic event in the late Brunhes chron. *Earth Planet. Sc. Lett. 310*, 508-517

Kirschvink J.L., 1980, The Least-Squares Line and Plane and the Analysis of Palaeomagnetic Data. *Geophys. J. R. Astr. Soc. 62*, 699-718.

Kochegura, V. V., Pisarevsky, S. A., 1994. Paleomagnetic Study of the Holocene and Late-glacial Sediments of the North-Western Russia. XXI International Union of Geodesy and Geophysics General Assembly. Boulder, USA, Abstracts, A173.

Kontny, A., de Wall, H., 2000, Case studies on the use of temperature-dependent susceptibility for the characterization of magneto-mineralogical changes during metamorphism. Phys. Chem. *Earth, Part A Solid Earth Geod. 25(5)*, 421–429., doi:10.1016/S1464-1895(00)00066-1.

Korte, M., Constable, C., 2005a, Continuous geomagnetic field models for the past 7 millennia: 2. CALS7K. Geochem., Geophys., Geosys. 6, Q02H16, doi:10.1029/2004GC000801.

Korte, M., Constable, C., 2005b, The geomagnetic dipole moment over the last 7000 years - new results from a global model. *Earth Planet. Sci. Let. 236*, 348–358.

Laj, C., Kissel, C. Roberts, A. P., 2006, Geomagnetic field behavior during the Iceland Basin and Laschamp geomagnetic excursions: A simple transitional field geometry? *Geochem. Geophys. Geosyst*. *7*, Q03004, doi:10.1029/2005GC001122.

Laj, C, Channel, J. E. T., 2007, Geomagnetic excursions. In: Kono M, editor. Treatise on geophysics. Amsterdam: Elsevier; p. 373–416. http://dx.doi.org/10.1016/b978-044452748-6/00095-x

Langereis, C. G., Van Hoof, A. A. M., Rochette P., 1992, Longitudinal confinement of geomagnetic reversal paths as a possible sedimentary artifact. *Nature 358*, 228–230. http://dx.doi.org/10.1038/358226a0

Lund, S. P., Williams, T., Acton, G., Clement, B., Okada, M., 2001, Brunhes epoch magnetic field excursions recorded in ODP Leg 172 sediments. In: Keigwin, V., Rio, D., and Acton, G., editors. Proceedings of the Ocean Drilling Project, Scientific Results. 172, Art. #10, 18 pages. http://dx.doi.org/10.2973/odp.proc.sr.172.216.2001

Lund, S. P., Stoner, J. S., Channell, J. E. T., Acton, G., 2006, A summary of Brunhes paleomagnetic field variability recorded in Ocean Drilling Program cores. *Phys. Earth Planet. Int, 156*, 194-204. DOI: 10.1016/j.pepi.2005.10.009

Lund, S. P.. Platzman, E., Thouveny, N. Camoin, G., 2007, Evidence for Two New Paleomagnetic Field Excursions ~2,500 and ~12,500 Years Ago from the South Pacific Ocean Region (Tahiti). AGU, Fall Meeting, abstract #GP42A-05

Lund, S. P., Platzman, E., Thouveny, N., Camoin, G., Yokoyama, Y., Matsuzaki, H., Seard, C., 2008. Evidence for Two New Magnetic Field Excursions (11,000 and 13,000 Cal Yrs BP) from sediments of the Tahiti Coral Reef (Maraa tract). AGU, Fall Meeting, abstract #GP21B-0786

Marco, S., 2002, Late Pleistocene paleomagnetic secular variation from the Sea of Galilee, *Israel. Geophys. Res. Lett. 29(21)*. doi:10.1029/2001GL014038.

Marsh, E., Estrella, D., Novellino, P., Moreiras, S., Lucero, N., Lucero, M., Sergo, F., Bosicovich, Y., Ayala, A., Yebra, L., Lucero, G., Frigolé, C., Nami, H., Moyano, R., Gava, E., Heredia, P., 2013. Recientes investigaciones en Barrancas, Maipú, Mendoza. Poster presented at XVIII Congreso Nacional de Arqueología Argentina https://www.academia.edu/5247468

Merrill, R. T., McFadden, P. L., 2005, The Use of Magnetic Field Excursions in Stratigraphy. Quat. Res., 63, 232–237.

Moreiras, S., Marsh, E., Nami, H.G., Estrella, D., Durán, V., 2013. Holocene Geomorphology, Tectonics, and Archaeology in Barrancas, Arid Southern Andes (33º S). ☐*Appl. Geogr, 42*, 217-226.

Mörner, N.A., 1977. The Gothenburg Magnetic Excursion. *Quat. Res.* 7, 413-427.

Nami, H. G., 1995. Holocene Geomagnetic Excursion at Mylodon Cave, Ultima Esperanza, Chile. *J. geomag. Geoelect. 47*, 1325-1332.

Nami, H. G., 1999a, Possible Holocene Excursion of the Earth's Magnetic Field in Southern South America: New Records from Archaeological Sites in Argentina. Earth Planets Space, 51, 175-191.

Nami, H. G., 1999b. Probable middle Holocene geomagnetic excursion at the Red rock archaeological site, California. *Geofís. Int. 18*, 239-250.

Nami, H. G., 2006, Preliminary Paleomagnetic Results of a Terminal Pleistocene/Holocene Record from Northeastern Buenos Aires Province (Argentina). *Geofizika 23*, 119–141.

Nami, H. G., 2011, New detailed paleosecular variation record at Santa Lucía archaeological site (Corrientes province, northeastern Argentina). *Geofis. Int. 50*, 163-175

Nami, H. G., 2012. New Detailed Holocene Paleomagnetic Records with Anomalous Geomagnetic Field Bahavior in Argentina. *Geoacta 37*, 83-116.

Nami, H. G., 2015. Detailed Paleomagnetic Records from Ecuador and New Evidence for the Geomagnetic Field Excursion during the Late Pleistocene-Holocene. *Geofis. Int. 54*, 127-148.

Nami, H. G., Sinito, A. M., 1993. Evidence of a Possible Excursion of the Geomagnetic Field Registered during the Late Holocene in the Province of Chubut, Argentina. Geoacta, 20, 19-26.

Nami, H.G., de la Peña, P., Vásquez, C. Feathers, J., Wurz, S., 2016. Paleomagnetic Results and New Dates from Late Pleistocene and Holocene Deposits from Klasies River Cave 1, South Africa. *S. Afr. J. Sci. 112(11/12)*, Art. #2016-0051, 12 pages. http://dx.doi.org/10.17159/ sajs.2016/20160051.

Nelson, F. E., Wilson, G. S., Shipboard party, 2009. Environmental magnetism and excursion record of the Pleistocene-Holocene transition in marine cores, West Coast South Island, New Zealand. *Geophys. Res. Abstacts 11*, EGU2009-430.

Nowaczyk, N. R., Frederichs, T. W., Eisenhauer, A., Gard, G., 1994. Magnetostratigraphic data from late Quaternary sediments from the Yermak Plateau, Arctic Ocean: evidence for four geomagnetic polarity events in the last 170 ka of the Brunhes Chron. *Geophys. J. Int. 117* 453-471

Nowaczyk, N.R., Knies, J., 2000. Magnetostratigraphic results from the eastern Arctic Ocean: AMS 14C ages and relative paleointensity data of the Mono Lake and Laschamp geomagnetic reversal excursions. *Geophys. J. Int. 140*, 185–197

Oviedo, E. S., 1989. Un Sistema de Computación para Análisis de Datos Paleomagnéticos, su Aplicación al Estudio de Datos Paleomagnético de Sedimentos de la Cuenca Neuquina. Doctoral dissertation, FCEFyN, University of Buenos Aires, 178 pp.

Parkes, P. A., 1986. Current Scientific Techniques in Archaeology. St. Martin´s Press, New York, 190 pp.

Petrova, G. N., Pospelova, G. A., 1990. Excursions of the magnetic field during the Brunhes chron. *Phys. Earth. Plan. Int. 63*, 135-143.

Petrovský, E. D., Kapička, A., 2006. On determination of the Curie point from thermomagnetic curves. *J. Geophys. Res. Solid Earth, 111(12)*, 1–10, doi:10.1029/2006JB004507.

Platzman, E. S., Lund, S., Camoin, G., Thouveny, N., 2010. Geomagnetic Secular Variation Determined from Paleomagnetic Observations in Late Quaternary (8-16,000 YBP) Carbonates From The South Pacific Ocean. Abstract presented at 2010 Fall Meeting, AGU, San Francisco, Calif., 13-17 Dec.

Raspopov, O.M., Dergachev, V.A., Goos'kova, E.G., 2003. Ezekiel's vision: Visual evidence of Sterno-Etrussia geomagnetic excursion? *Eos, Transactions AGU 84*, *9,* 77–83 (84: doi: 10.1029/2003EO090001)

Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Ramsey, C. B., Buck, C. E., Cheng, H., Edwards, R L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Haflidason, H., Hajdas, I., Hatté, C., Heaton, T. J., Hoffmann, D. L., Hogg, A. G., Hughen, K. A., Kaiser, K. F., Kromer, B., Manning, S. W., Niu, M., Reimer, R. W., Richards, D. A., Scott, E. M., Southon, J. R., Staff, R. A., Turney, C. S. M., van der Plicht, J., 2013. Intcal13 and Marine13 Radiocarbon Age Calibration Curves 0–50,000 Years Cal Bp. Radiocarbon, 55, 1869-1887.

Saarnisto, M., Saarinen, T., 2001. Deglaciation chronology of the Scandinavian Ice Sheet from the Lake Onega Basin to the Salpausselkä End Moraines. *Global Planet. Ch*. *31*, 387-405.

Singer B., 2014. A Quaternary geomagnetic instability time scale. *Quat Geochronol*., 29–52. http://dx.doi.org/10.1016/j.quageo.2013.10.003

Sinito, A.M., Nuñez, H.J., 1997. Paleosecular Variations Recorded on Lake Sediments from South America. *J. Geomagn. Geoelectr. 49*, 473–483

Sinito, A. M., Nami, H. G., Gogorza C., 1997. Analysis of Palaeomagnetic Results from Holocene Sediments Sampled at Archaeological Excavations in South America. *Quat. S. Am. Antarc. Penninsula 10*, 31-44.

Stuiver, M., Reimer, P. J., 1993. Extended 14C data base and revised CALIB 3.0 14C age calibration program. *Radiocarbon 35*, 215-230.

Tarling D., 1983. Paleomagnetism: Principles and Applications in Geology, Geophysics, and Archaeology, Chapman and Hall, New York, 379 pp. http://dx.doi.org/10.1007/978-94-009-5955-2

Thouveny, N., Creer, K. M., 1992. Geomagnetic excursions in the past 60 ka: Ephemeral secular variation features. Geology, 20, 399–402. http://dx.doi.org/10.1130/0091-7613(1992)020<0399:GEITPK>2.3.CO;2

Torsvik T., 1992. IAPD, Interactive analysis of Palaeomagnetic Data. Manual. NGU, N-7002, Trondheim, 51 pp.

Verosub, K., Banerjee, S. K., 1977. Geomagnetic excursions and their paleomagnetic record. *Rev. Geophys. 15*, 145–155. http://dx.doi.org/10.1029/RG015i002p00145

Zhu, R. X., Coe, R. S., Zhao, X.X., 1998. Sedimentary record of two geomagnetic excursions within the last 15,000 years in Beijing, China. *J. Geophys. Res., 103(B12)*, 30323-30334.

Zijderveld, J. D. A., 1967. AC demagnetization of rocks: Analysis of results. In: Collinson, D.W., Creer, K. M., Runcorn, S. K., (Eds.), Methods in Paleomagnetism, pp. 254–286, Elsevier, Amsterdam.