

Possible Holocene excursion of the Earth's magnetic field in southern South America: New records from archaeological sites in Argentina

Hugo G. Nami^{1,2}

¹Laboratorio de Paleomagnetismo "Daniel A. Valencio", Departamento de Ciencias Geológicas, Facultad de Ciencias Exactas, Físicas y Naturales, Universidad de Buenos Aires, Ciudad Universitaria (Pabellón II), (1428) Buenos Aires, Argentina

²Programa de Estudios Prehistóricos (CONICET), B. Mitre 1970 Piso 5 "A", Buenos Aires (1039), República Argentina

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Palaeomagnetic studies were carried out in several archaeological and palaeontological sites across Argentina and Chile. Remanence directions far removed from the present magnetic field, probably corresponding to a field excursion were recorded in several stratigraphic sections spanning ~ 11 to 2 ky bp. Detailed palaeomagnetic data from 235 cores obtained in six sections from archaeological sites in Argentina are reported. Stability of the NRM was analyzed by progressive thermal and alternating field demagnetization and ChRM directions determined in most cases. Computed VGPs from those directions tend to be concentrated over North America, Europe, Eastern Asia and Africa. Using 275 VGPs a palaeomagnetic pole that is $\sim 20^\circ$ apart from the Earth's rotation's axis was obtained.

1. Introduction

Sedimentary deposits from archaeological sites, caves and rockshelters have been the subject of paleomagnetic research for many years. These investigations were useful in examining paleomagnetic secular variation (PSV) at different localities and periods (e.g. Elwood, 1971; Kopper and Creer, 1973; Creer and Kopper, 1974; Papamarinopoulos and Creer, 1983; Noël and Thistlewood, 1989; Schmidt and Partridge, 1991). These studies also allowed the observation of geomagnetic field (GF) excursions and reversions (e.g. Kopper and Creer, 1976; Lovlie and Sandness, 1987; Parés and Pérez-González, 1995).

Recently, several palaeomagnetic results were obtained from cave sediments and archaeological sites from southern South America. They yielded evidence about PSV and a possible excursion of the GF occurred during the Holocene (Nami and Sinito, 1991, 1993; Nami, 1995; Nami *et al.*, 1995, 1998; Sinito *et al.*, 1997).

The study of the behaviour of the GF during excursions and reversals is extremely complex due to many variables affecting the palaeomagnetic recording process and the nature of the record (Merrill and McElhinny, 1983; Bogue and Merrill, 1992). However, though far from ideal, sedimentary sequences are suitable recording materials because they allow continuous stratigraphic analysis. Sediments have also a broad geographical distribution and are datable by ^{14}C .

In this sense, the archaeological and paleontological sedimentary deposits located in Argentina and Chile have shown that they may contribute to the knowledge of the past GF behaviour (e.g. Nami, 1995; Nami *et al.*, 1995; Sinito *et al.*, 1997). Therefore, in this paper palaeomagnetic results obtained in six new sections from archaeological sites are re-

ported. Additionally, a summary of the evidence of a probable GF excursion occurred in southern South America during the latest Pleistocene and Holocene is reported.

2. The Sampling Sites and Age of Deposits

For archaeological purposes, only sedimentary sequences corresponding to the end of the Pleistocene and to the Holocene (~ 11 –0.5 ky bp) were sampled. They are located in NW, NE and southern Argentina (Fig. 1). A brief description of the archaeological sites follow.

2.1 Alero de las Circunferencias (Pintocayoc 1) (AC)

AC ($22^\circ 56'\text{S}$, $65^\circ 25'\text{W}$) is a rockshelter located in the Humahuaca Department, Jujuy Province (NW Argentina). It was excavated by Hernández Llosas who identified a significant archaeological sequence in a ~ 2.5 m deep deposit (Hernández Llosas *et al.*, 1994). Seven layers were observed. These have different colours depending on the type of sedimentary matrix and vestige left: e.g. charcoal resulting from combustion, bones and other archaeological remains. The whole sequence is composed of fine sand (Bayarski *et al.*, 1995).

Fifty-five samples were collected from the following layers: 5 (samples 1 to 15), 6 (16 to 54) and 7 (sample 55) (Fig. 2A).

Radiocarbon dates obtained from charcoal in the sampled section are as follows: layer 5: 7850 ± 110 (URU-0084), layer 6: 9190 ± 110 (LP-628), 9180 ± 230 (LP-449) and, layer 7: 10340 ± 50 (Beta-79849) and 10720 ± 150 (LP-503) years b.p.

2.2 Arroyo Yará (AY)

AY ($26^\circ 0'\text{S}$, $55^\circ 21'\text{W}$) is an open air archaeological site located in the shorelines of the Yará creek at Puerto Esperanza village, Misiones Province (NE Argentina).

During the spring of 1993, a 0.6×0.6 m test pit up to 0.6 m deep was excavated by the archaeologist J. Mujica and the author. Only one stratum of brown clay overlying

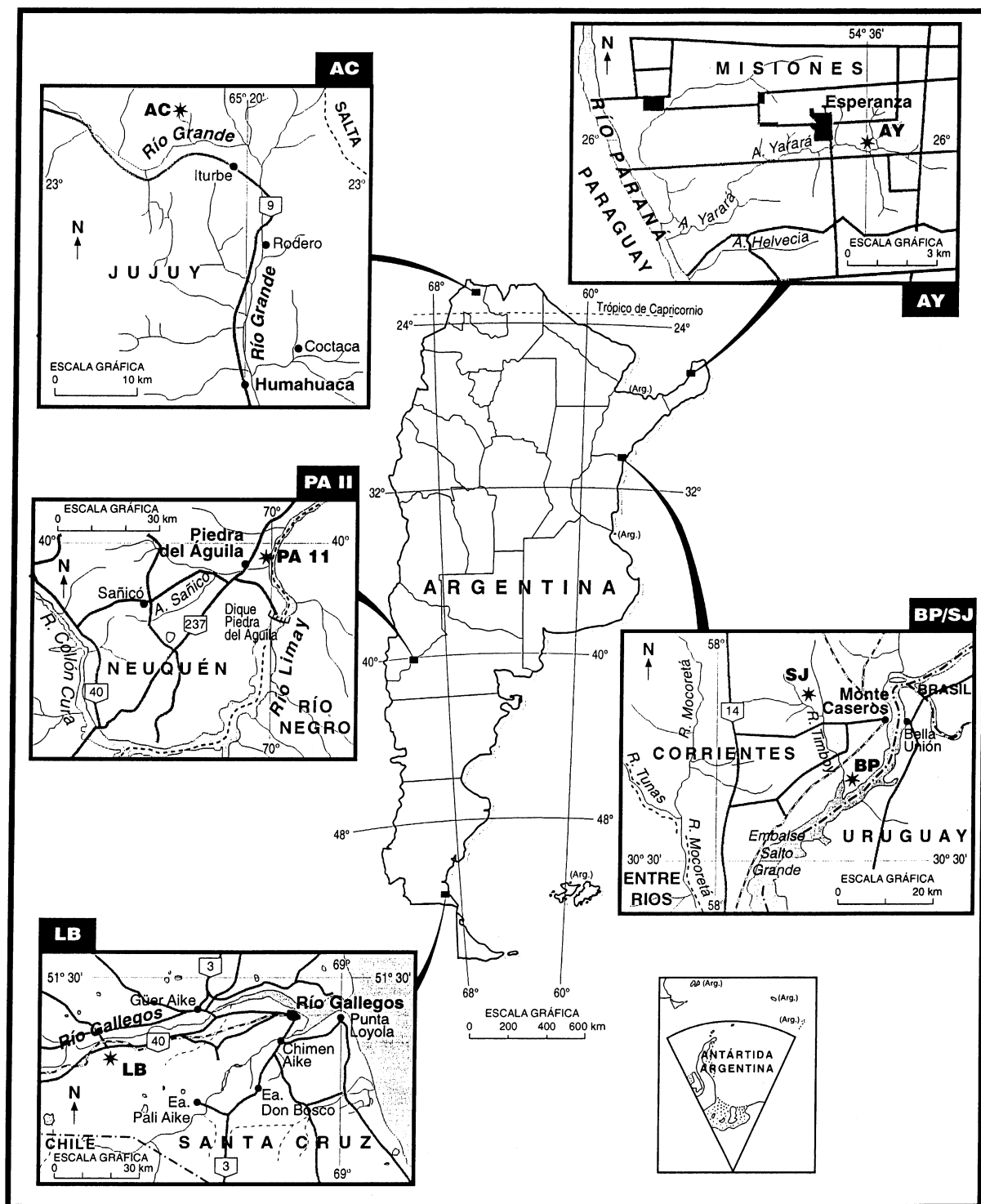


Fig. 1. Map of Argentina and location of the sampling sites mentioned in the text. AC: Alero de las Circunferencias, AY: Arroyo Yará, BP: Barranca Pelada, SJ: San Juan, PA11: Piedra del Águila 11 and, LB: Las Buitreras.

the basalt bedrock at this place was sampled ($n = 14$) for palaeomagnetic purposes (Fig. 2C).

Archaeological artifacts were found in the whole clay layer. Belonging from this archaeological level, there are surface archaeological artifacts, including lithic waste and stone tools commonly called “cleaves curves” or bifaces with boomerang form. According to Brazilian archaeolo-

gists, these artifacts characterized the “Humaitá tradition” dated between ~ 7 and 1 ky bp (Schmitz, 1987).

2.3 Barranca Pelada (BP)

BP de Itacumbú ($30^{\circ}15'S$, $57^{\circ}37'W$) is located on the Uruguay river shoreline, 19 km to the South of Monte Caseros village, Corrientes Province (NE Argentina).

The sampled profile is 1 m thick and 1.10 m wide. Three

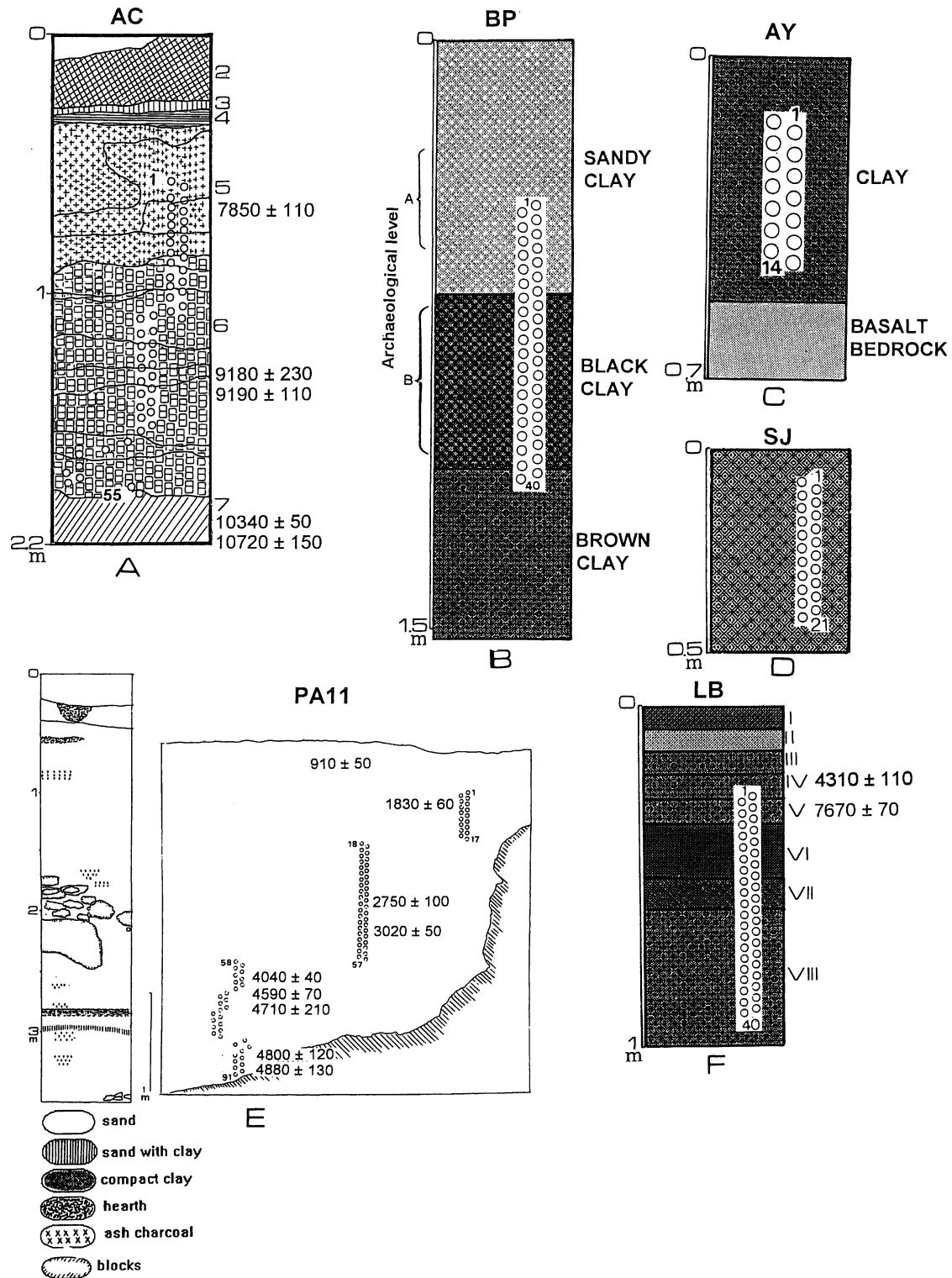


Fig. 2. Schematic stratigraphic profiles showing the sampled sections with location of the palaeomagnetic sampling related to stratigraphy. Only ^{14}C dates are given in the archaeological excavation. Numbers to the right of the sections show numbers of layers and those on the cylinders' top and bottom show the correlative order of the samples. A) Alero de las Circunferencias, B) Barranca Pelada, C) Arroyo Yará, D) San Juan, E) Piedra del Aguila 11. Right: schematic stratigraphic profile. Left: Excavation section showing the sampling location, F) Las Buitreras.

natural strata can be seen I, II and III. Level I is mostly sand, and II and III are dark brown clays (Fig. 2B). The sediments have abundant fine grain quartz and some calcium carbonate with cubic structure (Smorczewski, 1994).

Forty samples were collected from the lower part of layer I (samples 1 to 11), layer II (12 to 37) and the upper portion of layer III (38 to 40).

According to Mujica (pers. comm., 1994) there are two

archaeological levels. "A" in the upper section between 0.6–0.8 m and "B" approximately at 0.9–1.05 m deep. Projectile points found in this site are similar to those from the "Umbú tradition" dated between 6 and 0.3 ky bp in many sites in SE Brazil, NE Argentina and Uruguay (Schmitz, 1987; Rodríguez, 1992).

2.4 Estancia San Juan (SJ)

SJ (30°S, 57°44'W) is located at a probable shoreline of an ancient bed of the Timboy creek, 22 km to the Northwest of Monte Caseros, Corrientes Province. The profile is 0.6 m thick and 1 m wide (Fig. 2D). Archaeological remains are found everywhere from the surface to 0.4 m deep.

The deposit is only one highly compacted dark gray stratum, probably a redeposited volcanic sediment. It is composed of medium to fine subangular to rounded quartz, chalcedony clasts and some angular lithics (Smorczewski, 1994). The samples ($n = 21$) were obtained from the surface to 0.4 m deep. Archaeological remains include bifacial artifacts and "bolas" stones. In the Salto Grande area, very close to Monte Caseros, similar remains belong to the middle Holocene (Rodríguez, 1992).

2.5 Piedra del Aguila 11 (PA11)

PA11 is a rockshelter about 9 m long and 5 m wide, located in the banks of the Limay River (40°02'S, 70°W), 4 km to the north of the homonymous village in the Neuquén Province (SW Argentina). It was excavated by Sanguinetti de Bórmida and Curzio (1996) during several field seasons between 1985 and 1991. The excavations yielded an interesting archaeological sequence in a ~3.6 m deep sedimentary deposit.

Samples ($n = 91$) were collected on the squares 24, 4 and 12 of the southeastern profile that is ~3.5 m deep and ~4.5 m wide (Fig. 2E). From the surface to 3.6 m depth, the sediment is composed of gray sand with lenses of human hearths' ashes and silty sand or clay embedded in the matrix. The bottom of the excavation is composed of clear brown silty sand (Sanguinetti de Bórmida and Curzio, 1996).

The excavation was dated using ash charcoal collected at different levels. The radiometric dates are: 1830 ± 60 (Beta-41619), 2750 ± 100 (Beta-50675), 3020 ± 50 (LP-190), 4040 ± 40 (Beta-39945), 4590 ± 70 (Beta-50677), 4710 ± 210 (Beta-50676), 4800 ± 120 (Beta-50678), 4880 ± 130 (Beta-50679) (Sanguinetti de Bórmida and Curzio, 1996).

2.6 Las Buitreras Cave (LB)

LB (51°44.52'W, 70°10.28'S) is located 60 km to the west of the Río Gallegos city, Santa Cruz Province (southern Argentina). It is a big cave about 10 m long by 20 m wide with a 3 m deep sedimentary deposit. It was excavated by Sanguinetti de Bórmida in different field seasons during the '70 and '90s.

Eight layers were identified in the deposit (Sanguinetti de Bórmida, 1976). The sediments have a homogeneous mineralogical composition formed by basic volcanic and pyroclastic elements (Scasso, 1997). Layers I to V have the highest proportions of organic material suggesting abundant anthropogenic input (Eugenio, 1997).

Layers I and III were ^{14}C dated at 670 ± 60 (Beta-71985) and 750 ± 60 (Beta-71984) respectively, layer IV at 4310 ± 110 (GAK-6051) and layer V was dated at 7670 ± 70 (CSIC-372) years B.P. In layer VII there were blocks fallen down from the cave's wall, probably during a catastrophic move-

ment. Similar phenomena occurred in other rockshelters in southern Patagonia. This event has been dated with a ~9.5 ky bp minimum age (see Saxon, 1976; Nami, 1987, 1996; Prieto, 1991).

Extinct fauna bones of *Mylodon cf. listai* and *Hippidion sp.* were recovered from layers VI to VIII. Similar faunal remains from archaeological sites near this cave were dated as not younger than 10.5 ky bp (Nami and Nakamura, 1995; Nami, 1996). This fact suggest that Ice Age animals in southern Patagonia became extinct ~10 ky bp (Borrero, 1997).

Forty samples were collected in southern profile from layers IV (sample 1), V (2 to 7), VI (8 to 15), VII (16 to 20) and VIII (21 to 40) (Fig. 2F).

3. Palaeomagnetic Analysis

3.1 Sampling and laboratory procedures

Samples were collected in cylindrical plastic and bronze containers 2.5 cm long by 2.5 cm in diameter in AC, AY and PA11 and 2 cm at BP, SJ and LB. The cylinders were carefully pushed into the sediment so that each specimen overlaps the previous one about 50% and their strike and dip were measured using a Brunton compass and inclinometer. Once removed, they were consolidated with sodium silicate. The stratigraphic position of each was carefully measured, registered, and sequentially numbered from the top to the bottom (Fig. 2). In some cases (AC, PA11 and LB) samples were not taken near the surface because the sediments were unconsolidated and they may have been disturbed by recent events, such as animal and/or human trampling.

Palaeomagnetic measurements were made using a 2G cryogenic magnetometer.

Stepwise alternating field (AF) and thermal demagnetization were used according to the nature of the sample containers and to determine the sediment response to different demagnetization procedures.

Sediments in plastic containers were subjected to progressive AF demagnetization in steps of 3, 6, 9, 12, 15, 20, 25, 30, 40 and 80 mT. Additional steps of 90, 100 and 110 were used for some samples. Specimens contained in bronze cylinders were subjected to thermal demagnetization in a Schonstedt TSD-1 demagnetizer in 50°C steps between 100° and 500°C, and additionally at 525° and 550°C.

The ChRM was isolated using principal component analysis (p.c.a.). The inherent scatter in directions was measured using the maximum angular deviation (MAD). This is the angle spanned by the standard deviation of the data perpendicular and parallel to the best fitting line (Kirschvink, 1980).

3.2 Results

According to the number of magnetic components and stability, remanence directions were qualified as: 1) "highly reliable" (HRe), with practically univectorial behaviour with decay towards the origin (e.g. Fig. 3a, 4f, 5b), 2) "moderately reliable" (MRe), with "noisy" behaviour during demagnetization and/or, multicomponent behaviour but a clear decay towards the origin or, well defined principal component but with erratic behaviour during final steps (e.g. Fig. 3d), 3) "poorly reliable" (PRe), with two or three components that could not be well isolated unless remagnetization circle analysis was used (Fig. 7), 4) "unreliable", with unstable behaviours. All samples rated as 3) and 4) were rejected

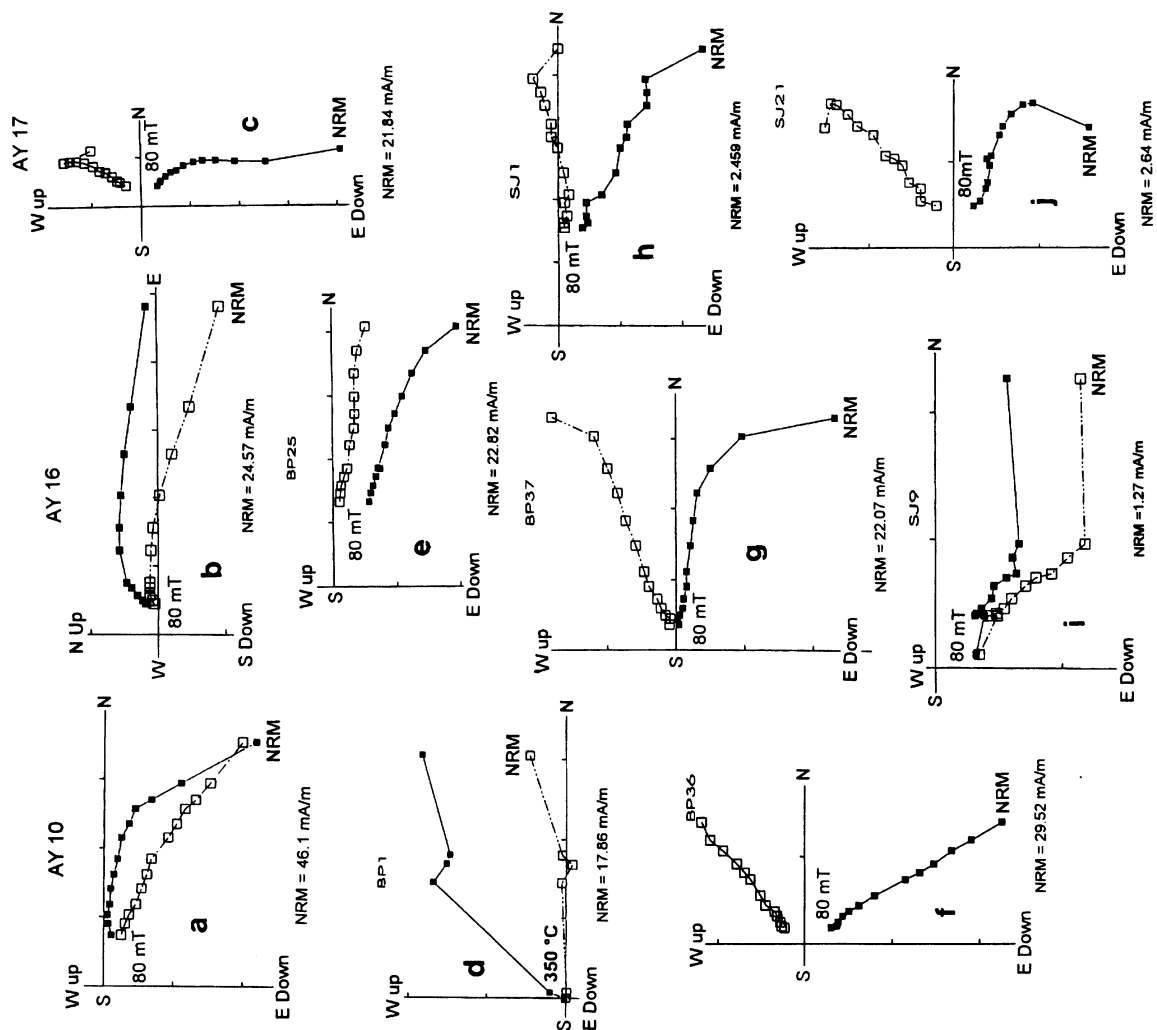


Fig. 4. Examples of vector projection diagrams for Arroyo Yará (a-c), Barranca Pelada (d-g) and San Juan (h-j) sites in north-eastern Argentina.

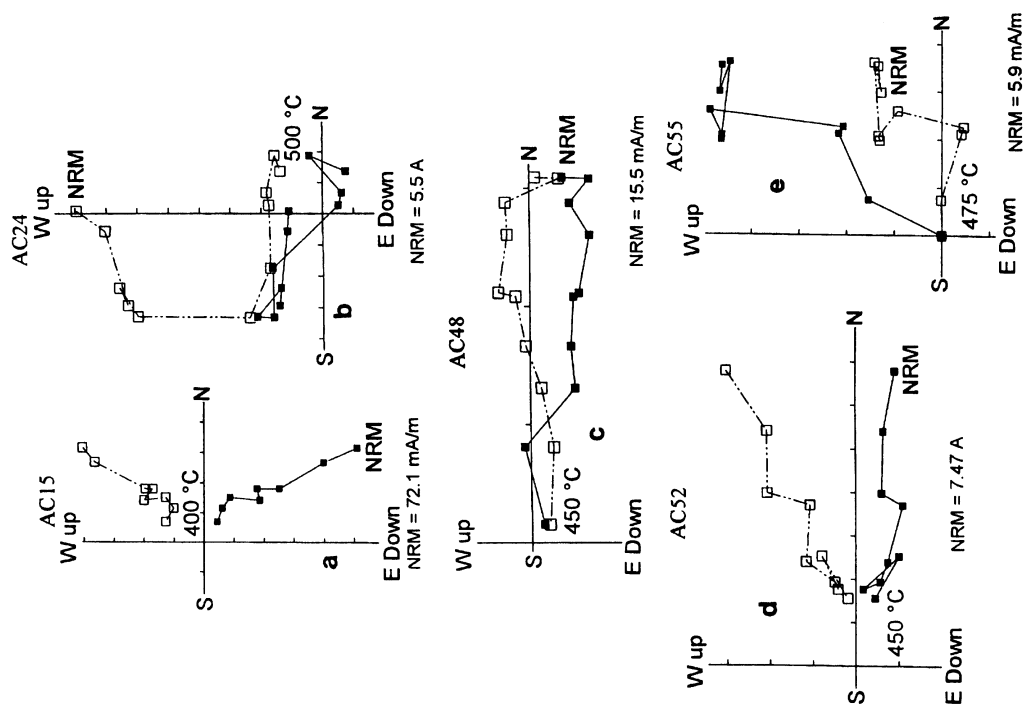


Fig. 3. Typical Zijderveld diagrams from Alero de las Circunferencias site. Most of the samples were thermally demagnetized. Solid symbols correspond to the projection onto the horizontal plane, while open symbols are projection onto the vertical plane.

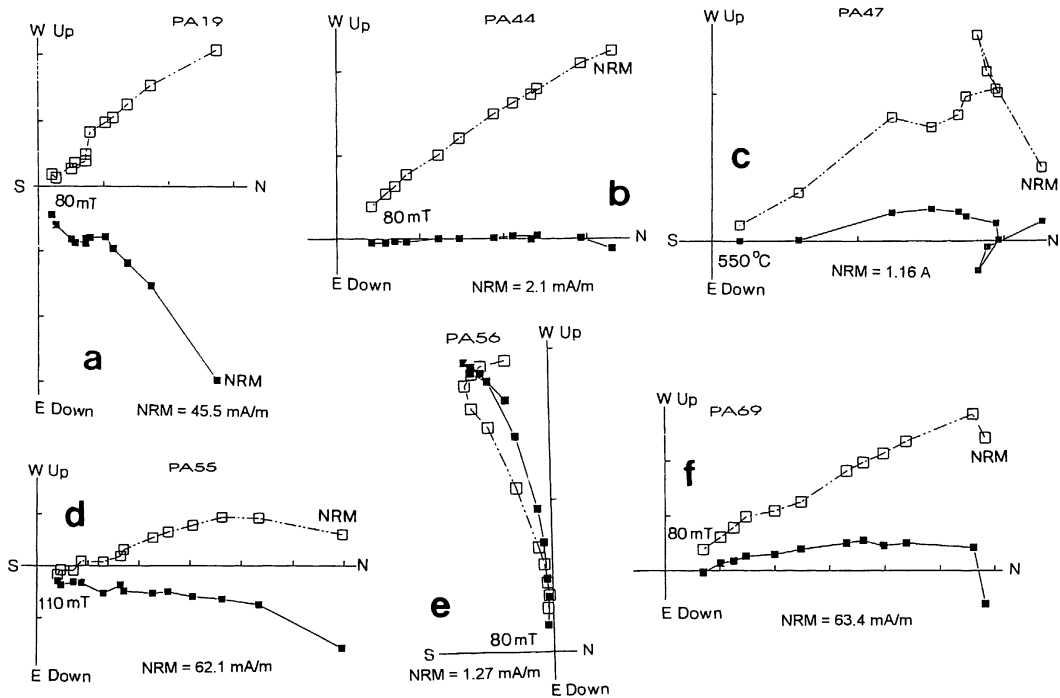


Fig. 5. Vector components diagrams showing the behaviour of typical samples cleaned using AF and thermal progressive demagnetization from Piedra del Aguila 11 site.

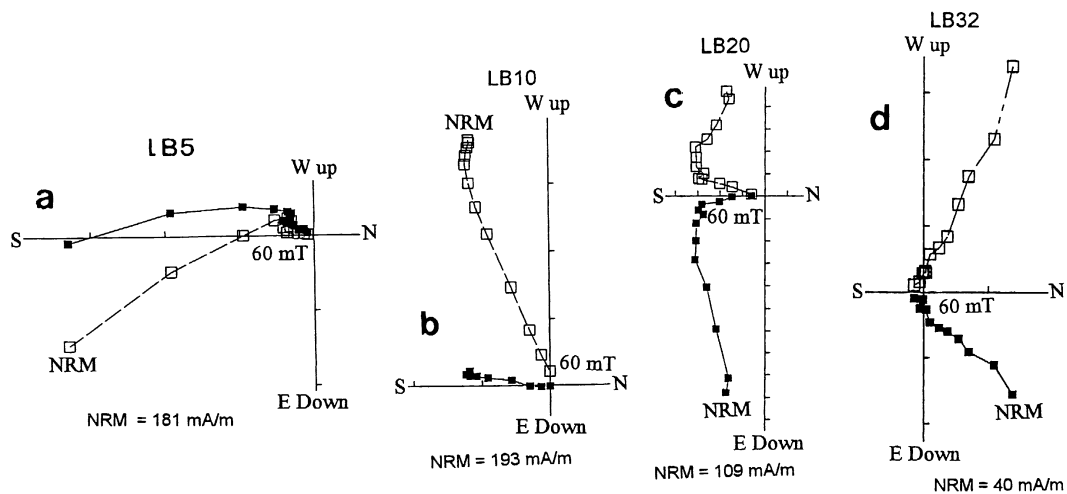


Fig. 6. Typical Zijderveld diagrams of stepwise demagnetization of four samples with normal, intermediate and reverse polarity from Las Buitreras site.

($n = 26$).

In general samples from each site showed a common pattern with similar reliability. They are as follows:

AC: Samples from this site did not show significant differences under thermal and AF demagnetization procedures. However, due to the nature of the containers, most samples were processed using thermal cleaning.

Vector projection diagrams (VPD) (Zijderveld, 1967) illustrated in Fig. 3 show samples with either single component remanence with high inclination (AC15, Fig. 3a) and low inclination (sample AC48, Fig. 3c). Some samples had

an overprint of the present geomagnetic field which was removed around 250°C (e.g. AC55, Fig. 3e) while others had two components, one with an anomalous southward direction (AC24, Fig. 3b).

Blocking temperatures between 450° and 500°C (Fig. 3) suggest that the magnetic minerals belong to the titanomagnetite series (Tarling, 1983; Butler, 1992).

AY: Only AF demagnetization was used in this core, which proved to be highly efficient. Most samples had two components with the second one decaying to the origin in the VDP diagrams (Figs. 4a–c). Some samples showed low while oth-

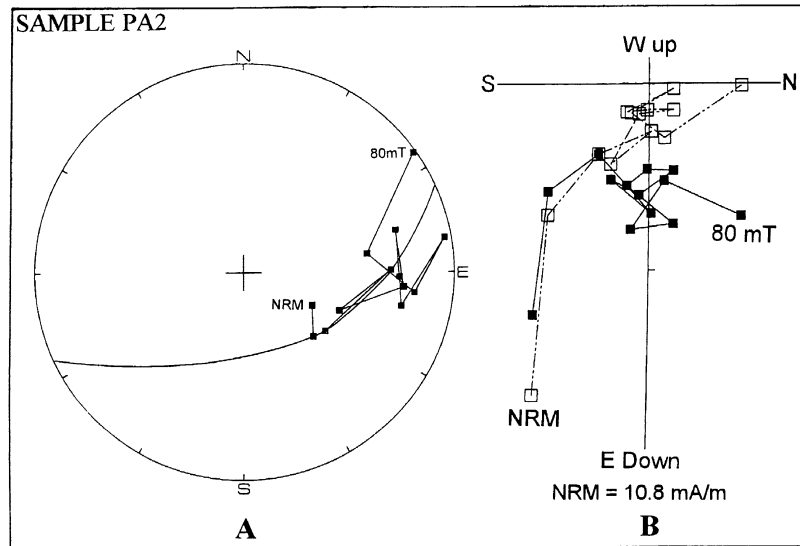


Fig. 7. Example of unreliable multicomponent sample to isolate directions from PA11 (#2) moving in a maximum circle. A) Stereographic projection, B) Zijderveld diagram.

ers high inclination values, but in all cases negative (YA10 and YA17, Figs. 4a and 4c). A few ones, such as YA16, had an easterly declination and inclination (Fig. 4b).

BP: Here AF demagnetization was more efficient than thermal cleaning. Using this procedure some samples were very unstable and therefore, they were rejected. Like in the case of AY, Zijderveld diagrams show that samples had either low (BP25, Fig. 4e) or high inclinations with north-easterly (BP36, Fig. 4f) to south-easterly directions (BP36 and BP37, Figs. 4f–g).

Samples show an important drop in the NRM intensity at 350°C (BP1, Fig. 4d) suggesting the presence of some sulphides in their magnetic mineralogy, probably pyrrhotite (Tarling, 1983; Butler, 1992). This mineral can also be suggested because in those samples cleaned by AF, the NRM was removed at fields higher than 60 mT.

SJ: AF demagnetization was highly efficient in these samples. Except for a soft viscous component that was easily removed between 3 and 6 mT, the samples had univectorial behavior with decay towards the coordinate's origin. SJ1, SJ9 and SJ21 are examples of this kind of sample (Figs. 4h, i and j).

PA11: Samples from this section did not show significant differences with AF and thermal demagnetization procedures. However, due to the nature of the containers, samples 40 to 42, 46, 47 and 74 to 91 were processed using thermal cleaning. The remaining ones (1 to 39, 44, 45 and 48 to 73) were demagnetized by AF cleaning.

Most of the samples were HRe with linear decay towards the origin (e.g. Figs. 5a–f), however some specimens showed a viscous component that was removed at 100–200°C (e.g. PA47, Fig. 5c).

Many samples showed either high (PA19, Fig. 5a) or low negative inclinations (PA55, Fig. 5d). A few showed a south-westerly direction (PA56, Fig. 5e).

Blocking temperatures at 450° to 550°C (Fig. 5c) suggest that the magnetic carrier belong to the titanomagnetite series

Table 1. Ranges of MAD values discriminated by sites.

Site	0–5° (%)	5.1–10° (%)	10.1–15° (%)	15.1–20° (%)
AC	2.8	33.3	63.9	–
AY	71.5	28.5	–	–
BP	38.2	41.2	17.7	2.9
SJ	4.8	85.7	9.5	–
PA11	36.7	48.9	10	4.4
LB	22.5	55	2.5	2.5

(Tarling, 1983; Butler, 1992).

LB: Samples subjected to thermal demagnetization were highly unstable. However, AF cleaning showed to be the more efficient for this core. As illustrated in Fig. 6, VPD shows clear southerly directions for samples LB5, LB10 and LB20 (Figs. 6a–c) while others show northerly directions and negative inclinations (e.g. LB32, Fig. 6d).

As represented in Table 1, MAD values were very low. The number and intervals of demagnetization steps used to isolate the ChRM and VGP positions are described in Table 2. All the sections show normal and intermediate polarity directions far from the present GF, while reversed polarities were recorded at AC and LB.

Figures 8 to 12 summarize the changes in the declinations and inclinations of the ChRM isolated for the sections reported here. The more conspicuous long declination and inclination departures are depicted between dashed lines and indicated with arrows.

AC magnetogram (Fig. 8) show strong swings in declination between samples 20 and 50 dated between ~10 and ~7 ky bp. There is also an important correlative shift toward higher negative values in inclination (over 40°).

Table 2. Values of characteristic remanent magnetization (ChRM), virtual geomagnetic pole positions and intervals of selected ChRM for each sample. Negatives values show negative inclination or VGP located in the southern hemisphere. Intervals of selected ChRM are given in mT or °C according thermal (T) or alternating field (AF) demagnetization procedures used. Or. = Origin in the Zijderveld diagram.

AC						
Sample	D°	I°	Long. E	Lat.	Int. ChRM	Cleaning
3	34	-68	80	52	0-200	T
6	33	-40	31	60	450-Or.	T
7	17	-38	22	74	0-Or.	T
8	51	-27	24	41	250-450	T
9	55	-37	33	39	100-250	T
10	5	16	304	59	400-Or.	T
11	37	-35	26	56	250-Or.	T
12	63	-30	30	31	350-450	T
13	59	-21	23	33	350-Or.	T
14	348	-78	121	45	200-Or.	T
15	61	-33	32	33	0-Or.	T
17	14	-19	343	71	100-Or.	T
18	21	6	336	57	250-500	T
20	24	-24	4	65	100-200	T
24	213	-6	170	-47	300-450	T
25	25	5	342	55	350-Or.	T
26	8	-53	83	77	300-400	T
27	345	-15	198	47	0-250	T
28	262	-47	176	4	300-425	T
29	3	-21	308	78	350-Or.	T
30	16	-11	352	65	300-Or.	T
32	334	-6	239	58	0-250	T
33	289	-50	180	27	0-300	T
35	275	-5	204	6	400-Or.	T
36	350	13	275	59	500-Or.	T
38	45	-30	24	47	12-25	AF
39	358	19	291	57	9-25	AF
41	46	-39	34	48	0-Or.	T
44	25	-24	6	63	0-200	T
45	11	-30	353	78	0-Or.	T
48	11	-8	326	68	200-Or.	T
50	359	-24	289	80	0-400	T
51	39	13	352	42	350-Or.	T
52	6	-25	326	79	0-Or.	T
54	37	-25	16	54	250-400	T
55	312	7	228	36	300-Or.	T
YA						
Sample	D°	I°	Long. E	Lat.	Int. ChRM	Cleaning
1	357	-1	298	64	25-60	AF
2	359	-17	301	73	25-Or.	AF
3	342	-42	217	74	25-Or.	AF
4	43	5	302	39	30-Or.	AF
5	9	-19	334	72	25-Or.	AF
6	353	-18	282	72	15-Or.	AF
7	3	-20	316	74	40-60	AF
8	43	-2	11	42	50-Or.	AF
9	5	25	312	50	20-60	AF
10	3	-31	322	80	9-40	AF
11	332	25	266	42	60-Or.	AF
12	60	-66	77	39	15-Or.	AF
13	42	-21	22	48	40-Or.	AF
14	46	-47	49	49	30-Or.	AF

Table 2. (continued).

BP						
Sample	D°	I°	Long. E	Lat.	Int. ChRM	Cleaning
1	318	-0.3	241	40	150-Or.	T
2	37	-24	13	51	0-250	T
8	284	25	230	5	350-Or.	T
9	10	-30	338	73	0-200	T
10	346	7	279	54	250-400	T
11	54	-19	22	36	0-150	T
13	350	-23	273	70	250-Or.	T
14	6	-17	317	68	100-Or.	T
15	25	-20	357	59	100-250	T
16	7	-17	321	67	200-Or.	T
17	31	-25	8	57	30-Or.	AF
18	350	-50	223	81	200-300	T
19	355	-23	288	71	30-Or.	AF
20	338	-43	223	70	30-Or.	AF
21	57	-23	26	35	0-150	T
22	15	-16	338	63	0-Or.	AF
23	16	-19	342	65	3-Or.	AF
24	7	-12	318	65	3-Or.	AF
25	20	6	336	51	3-Or.	AF
26	9	-9	322	63	250-400	T
27	17	17	327	48	3-Or.	AF
28	11	-12	328	63	6-Or.	AF
29	24	-23	357	61	6-Or.	AF
30	347	4	279	55	150-300	T
31	71	-30	37	24	300-400	T
32	29	12	344	45	0-Or.	AF
33	16	-35	358	72	3-Or.	AF
34	38	-16	8	48	3-Or.	AF
35	6	-60	99	78	3-100	AF
36	59	-23	27	33	0-Or.	AF
37	10	-22	330	69	6-Or.	AF
38	17	-42	16	74	0-200	T
39	28	-47	329	26	3-Or.	AF
40	342	-66	153	67	3-30	AF
SJ						
Sample	D°	I°	Long. E	Lat.	Int. ChRM	Cleaning
1	19	3	335	54	25-Or.	AF
2	360	1	302	59	3-15	AF
3	338	-38	230	68	3-Or.	AF
4	48	-52	47	49	6-Or.	AF
5	8	-33	335	76	6-Or.	AF
6	8	-22	326	70	15-40	AF
7	14	-20	339	66	3-Or.	AF
8	11	-49	34	80	3-Or.	AF
9	32	-46	333	25	3-Or.	AF
10	11	24	318	46	6-30	AF
11	1	-30	306	76	6-Or.	AF
12	341	-28	249	67	3-Or.	AF
13	25	-42	22	68	3-Or.	AF
14	17	-50	39	75	3-60	AF
15	16	-22	344	66	3-80	AF
16	1	-19	305	70	3-Or.	AF
17	14	20	323	47	3-Or.	AF
18	33	-46	35	61	3-Or.	AF
19	353	-32	274	76	6-50	AF
20	45	-18	15	43	3-20	AF
21	25	-39	18	66	3-Or.	AF

Table 2. (continued).

PA11						
Sample	D°	I°	Long. E	Lat.	Int. ChRM	Cleaning
1	41	-15	350	41	12-80	AF
3	64	-17	9	25	0-25	AF
4	49	-12	355	34	15-Or.	AF
5	53	-15	356	32	15-30	AF
6	24	-23	333	55	3-15	AF
7	20	27	330	59	15-25	AF
8	233	-84	122	32	0-15	AF
9	49	-5	353	32	50-Or.	AF
10	78	-8	15	12	0-12	AF
11	72	1	8	14	0-12	AF
12	78	-15	18	14	3-20	AF
13	90	0	20	0	60-Or.	AF
14	40	-25	353	46	30-60	AF
15	37	-34	358	52	3-Or.	AF
16	54	-11	0	30	20-Or.	AF
17	60	-42	22	38	60-Or.	AF
18	53	-19	3	34	0-40	AF
19	57	-17	5	31	30-Or.	AF
20	245	-71	143	20	60-Or.	AF
21	75	-4	12	13	0-20	AF
22	66	9	8	21	0-15	AF
23	41	-33	0	49	3-60	AF
24	38	-21	350	45	30-Or.	AF
25	17	-33	342	62	20-Or.	AF
26	9	-29	309	64	3-Or.	AF
27	341	-29	309	64	3-Or.	AF
28	338	-45	230	67	3-Or.	AF
29	12	-47	333	74	3-Or.	AF
30	352	-44	261	74	3-Or.	AF
31	29	-37	350	59	3-Or.	AF
32	4	-30	300	66	3-Or.	AF
33	8	-41	315	72	3-Or.	AF
34	128	-41	338	68	3-Or.	AF
35	359	-43	286	75	3-Or.	AF
36	2	-43	297	75	3-Or.	AF
37	1	-44	292	75	3-Or.	AF
38	4	-30	298	66	3-Or.	AF
39	355	-32	277	67	3-Or.	AF
40	16	-20	290	50	300-Or.	T
41	358	-40	284	73	450-Or.	T
42	8	-8	304	53	350-500	T
43	8	-41	313	72	3-Or.	AF
44	359	-35	287	69	3-Or.	AF
45	2	-27	295	64	3-Or.	AF
46	336	-12	255	45	250-450	T
47	352	28	273	64	300-Or.	T
48	352	-37	268	69	12-80	AF
49	6	-30	307	65	3-Or.	AF
50	30	-16	339	48	40-Or.	AF
51	1	-16	291	58	40-Or.	AF
52	2	-14	294	57	9-Or.	AF
53	35	-30	353	51	30-Or.	AF
54	3	-32	298	67	25-Or.	AF
55	42	8	342	32	9-Or.	AF
56	268	-28	187	8	40-80	AF
57	16	-35	324	61	30-Or.	AF
58	345	-25	261	60	12-Or.	AF

Table 2. (continued).

Sample	D°	I°	Long. E	Lat.	Int. ChRM	Cleaning
59	358	-30	286	66	3-Or.	AF
60	349	-21	270	59	3-Or.	AF
61	346	3	269	47	6-Or.	AF
62	36	-24	349	48	3-Or.	AF
63	3	-42	300	74	3-Or.	AF
64	32	-35	352	55	12-Or.	AF
65	355	-46	269	76	3-Or.	AF
66	351	-20	272	59	3-Or.	AF
67	60	-24	10	31	3-Or.	AF
68	356	-33	279	68	3-Or.	AF
69	354	-27	278	64	3-Or.	AF
70	6	-30	303	66	3-Or.	AF
71	2	-21	294	61	6-Or.	AF
72	12	-37	320	68	3-Or.	AF
73	1	-33	292	68	3-Or.	AF
74	4	-33	299	68	100-Or.	T
75	13	-38	335	31	300-Or.	T
76	272	-45	180	18	400-500	T
77	94	-55	50	20	200-300	T
78	344	9	269	43	350-450	T
79	360	-34	290	68	250-Or.	T
80	16	-27	317	56	300-Or.	T
81	341	-37	244	65	400-Or.	T
82	341	-34	248	63	200-Or.	T
83	6	-19	301	56	0-300	T
84	254	-38	173	2	100-250	T
85	28	-14	335	49	450-500	T
86	38	-50	15	58	150-Or.	T
87	356	-14	283	57	250-350	T
88	358	-31	285	67	300-Or.	T
89	340	-41	237	66	300-550	T
90	345	-47	234	74	150-Or.	T
91	360	-41	289	74	150-300	T

LB						
Sample	D°	I°	Long. E	Lat.	Int. ChRM	Cleaning
1	61	9	354	14	3-30	AF
2	350	-52	264	70	6-30	AF
3	35	-57	4	62	30-Or.	AF
4	90	-57	46	29	6-Or.	AF
5	175	27	102	-53	0-40	AF
6	29	-29	334	48	6-30	AF
7	347	-40	266	60	3-40	AF
8	355	31	285	22	40-Or.	AF
9	292	-68	173	49	50-Or.	AF
10	279	-70	163	44	3-Or.	AF
11	41	-77	69	65	3-80	AF
12	3	-52	298	71	3-80	AF
13	48	-24	353	35	12-30	AF
14	66	-22	8	24	0-Or.	AF
15	78	-44	28	27	20-40	AF
16	13	-48	318	66	3-Or.	AF
17	42	-50	3	53	0-Or.	AF
18	99	-43	42	14	12-30	AF
19	23	-79	86	70	4-80	AF
20	169	-16	97	-30	30-Or.	AF
21	60	-64	36	51	3-Or.	AF
22	352	-73	147	83	3-50	AF

Table 2. (continued).

Sample	D°	I°	Long. E	Lat.	Int. ChRM	Cleaning
23	360	-74	110	81	3-60	AF
24	18	-76	79	75	3-60	AF
25	4	-64	316	84	9-25	AF
26	10	-70	46	83	3-40	AF
27	27	-65	13	71	3-12	AF
28	28	-51	347	62	3-12	AF
29	31	-67	27	70	3-20	AF
30	353	-16	280	46	12-25	AF
31	50	-57	18	53	0-20	AF
32	43	-55	9	56	3-Or.	AF
33	66	-55	27	41	3-80	AF
34	31	-63	13	68	3-Or.	AF
35	350	-67	211	83	0-Or.	AF
36	306	-40	214	40	6-20	AF
37	51	-62	27	55	0-60	AF
38	7	-53	307	71	3-30	AF
39	349	-54	262	71	3-50	AF
40	15	-53	327	69	3-20	AF

BP shows gradual changes toward positive inclinations between samples 1 and 11 and particularly between 20 and 35 (Fig. 9). AY shows transitional negative to positive inclinations between samples 3 and 12 (Fig. 10B). SJ core also recorded a transitional zone defined by a gradual, negative to positive change in inclination between samples 8 and 14 (Fig. 10A). Relative chronologies for AY, BP and SJ suggest that the observed GF anomalous behaviour occurred in the middle to late Holocene.

In PA11, a significant but gentle eastward shift in the declination (over 40°) and a less conspicuous shallowing of the inclination can be observed in the upper part of the section between ~ 2.5 and 1.9 ky bp (Fig. 11). Figure 12 also illustrates the long pulses in declination and inclination during a possible excursion of the GF. Like in Mylodon Cave (Nami, 1995), LB records suggest a shift from normal to intermediate and reversed positions during the Late Pleistocene to early Holocene (Fig. 12). This fact occurs between samples 1 and 21 in layer IV to VII, that is between ~ 4 and ~ 10 ky bp.

Figures 13 and 14 illustrates the direction of the ChRM and corresponding virtual geomagnetic pole (VGP) positions for each section. It can be seen that generally VGP's are located

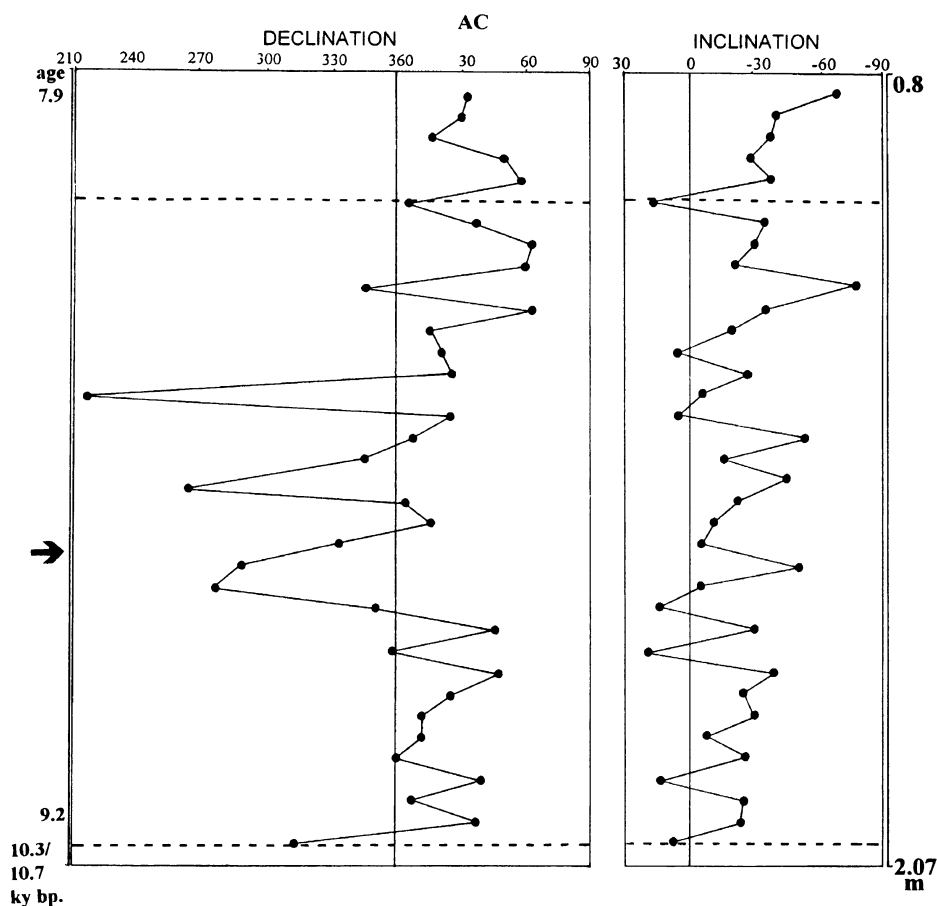


Fig. 8. Stratigraphic presentation of the profile of declination and inclination from Alero de las Circunferencias. The more conspicuous long declination and inclination departures are indicated by arrows between dashed lines. Chronologies in the sections are only shown when they have direct absolute dates by ^{14}C . Samples' depths are indicated to the right of the diagrams (Figs. 8 to 12).

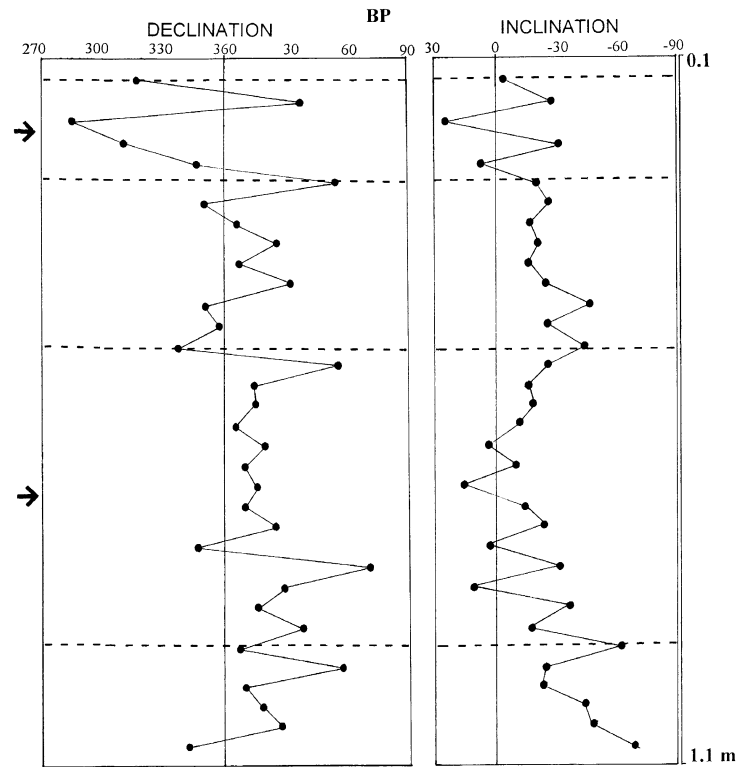


Fig. 9. Declination and inclination logs for the sequence of Barranca Pelada archaeological site.

in North America, Europe, Eastern Asia and Africa (Fig. 15).

Finally, Fig. 17B shows one geomagnetic pole computed from all VGP's located within a 40° window around the mean geomagnetic pole (cf. McElhinny *et al.*, 1974). It was isolated with 275 VGP obtained from samples at the Don Ariel Cave (Nami, 1994), the Mylodon Cave (Nami, 1995) and all the sites reported in this paper (Figs. 16, 17A). The mean geomagnetic pole is located at 336.7° W. Long., 68.65° S. Lat. with (A_{95}) 8.2° . This palaeopole shows a $\sim 20^\circ$ difference with respect to the Earth's rotation's axis (Fig. 17B). This fact, might suggest that PSV was not averaged, even considering that the data encompass ~ 8 kyr time span (cf. Hyodo *et al.*, 1993, p. 692). If this difference is a geomagnetic problem, these results might be partially attributed to the far-sided effect (Merrill and McElhinny, 1983).

4. Summary of Holocene Anomalous Magnetic Direction Records in Southern South America and Conclusion

The results reported in this paper show that many samples of Late-Pleistocene and Holocene deposits from Argentina recorded directions far removed from the present magnetic field, probably corresponding to a field excursion that occurred at sometime between 11 and ≤ 2 ky bp. This fact agrees with previous results obtained in other archaeological and palaeontological sites in Argentina and Chile, where remanence directions corresponding to an obliquely normal, obliquely reversed and reversed field polarity were found (Nami, 1994, 1995; Nami *et al.*, 1995, 1998; Sinito *et al.*, 1997). This situation suggests that the "Mylodon excursion" had a regional extent. Both shifts with N-R and R-N direc-

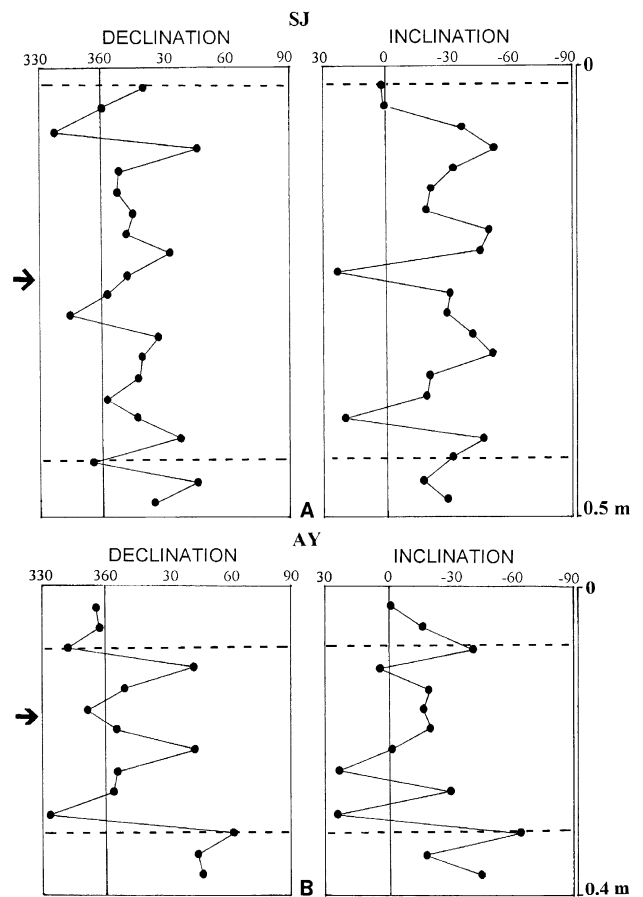


Fig. 10. Declination and inclination logs according to their stratigraphic sequence of San Juan (A) and Arroyo Yará (B) archaeological sites.

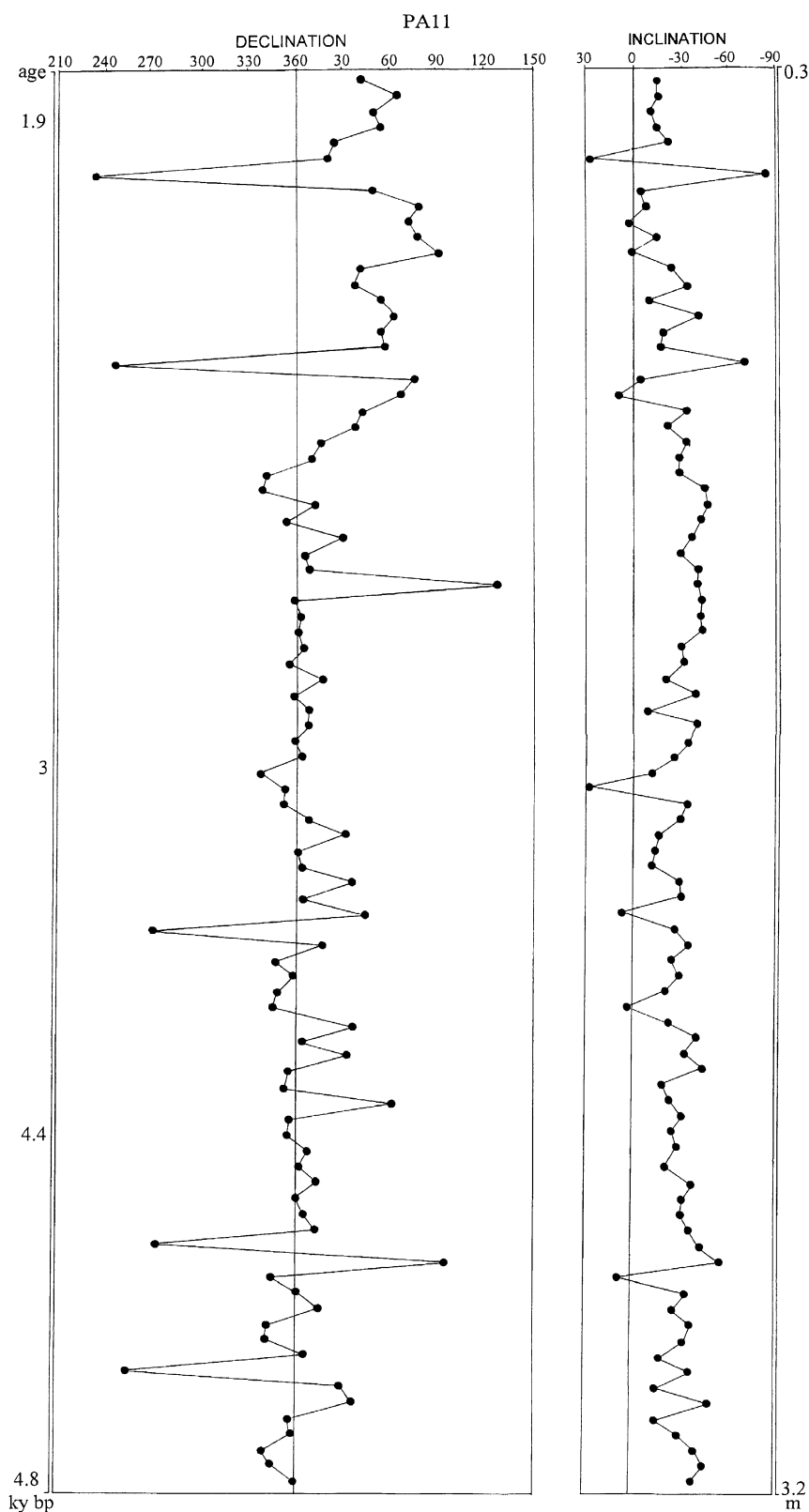
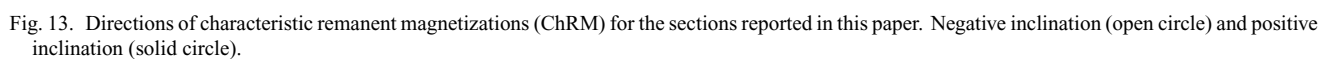
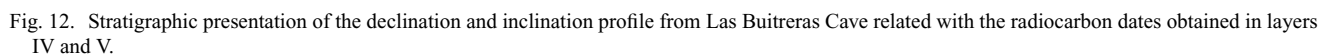


Fig. 11. Stratigraphic presentation of the profiles of declination and inclination from Piedra del Aguila 11 rockshelter related with the age of the deposit.

tions were clearly observed in Mylodon Cave and Angostura Blanca rockshelter (Fig. 18) in southern Argentina and Chile (cf. Nami, 1995). Information related to eleven records of this possible excursion are summarized in Table 3[†].

[†]Additional data might belong from the Buenos Aires province continental shelf (36°31'S, 53°59'W). Nabel and Spiegelman (1988) reported reversed polarity directions that they attributed to the Matuyama Polarity Epoch. However, the sampled sediment was supposed to belong to the Holocene (Nabel, 1988).



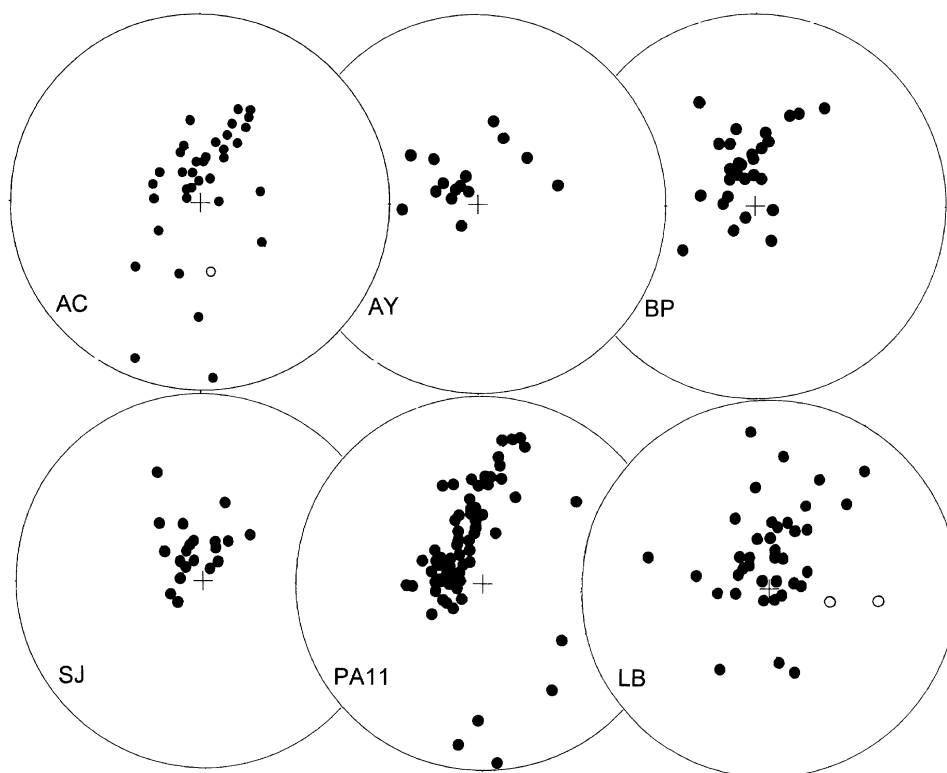


Fig. 14. Stereographic projection of virtual geomagnetic pole (VGP) calculated from directions of ChRM isolated in the sites mentioned in the text. Solid circles show those located in the northern hemisphere and open circles represented VGP located in the southern hemisphere. The centre of the projection is the geographic south pole.

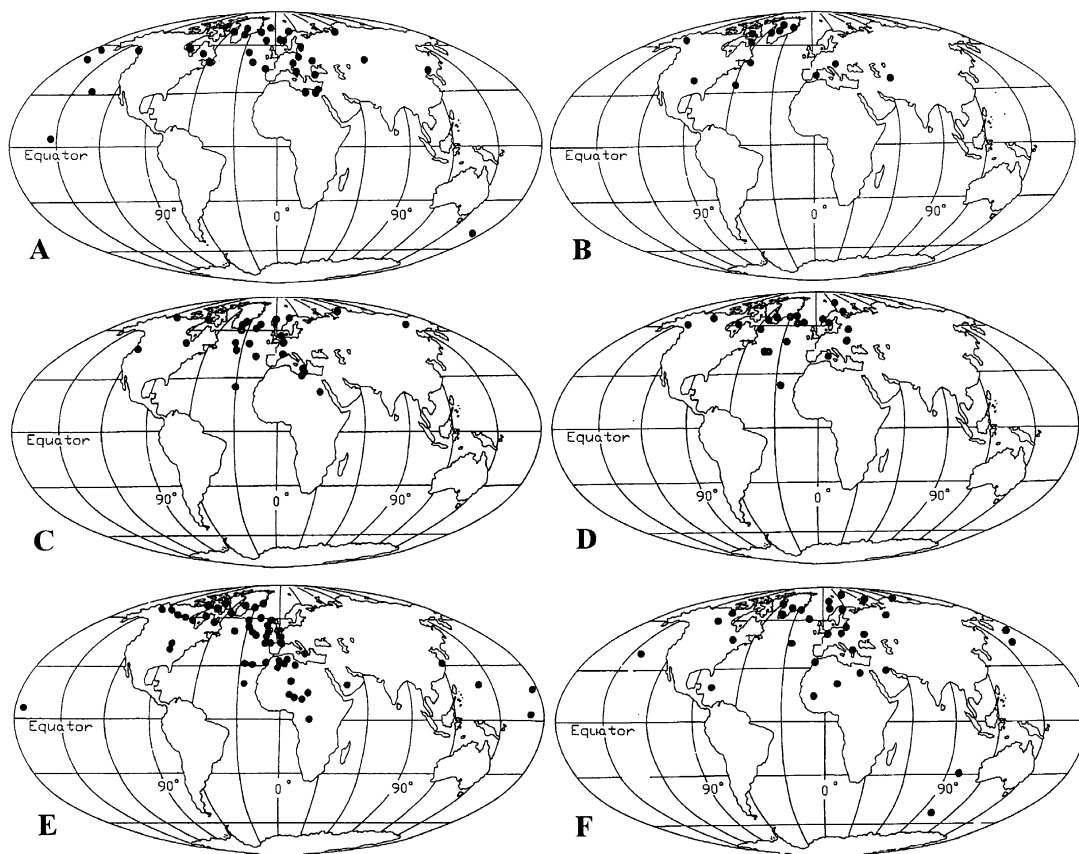


Fig. 15. VGPs paths plotted in the world map for the sites mentioned in the text. A) Alero de las Circunferencias, B) Arroyo Yará, C) Barranca Pelada, D) San Juan, E) Piedra del Aguila 11, F) Las Buitreras.

Table 3. Summary of archaeological sites, location, number and range of ^{14}C dates of sampled deposit, number, quality and polarity of the samples. References: *ND*: number of ^{14}C dates in the archaeological site, *: indicate indirect dates, *N*: Number of samples used in the analysis/total number of samples treated, *P*: Polarity of the core, *N* = Normal, *R* = Reverse, *I* = Intermediate. Intermediate considered when departure from the mean is greater than 30° (Quideller and Valet, 1996), *SQ*: Sample quality, *HRe*: Highly reliable, *MRe*: Moderately reliable, *PRe*: Poorly reliable.

Site	Coordinates	Age (ky bp)	<i>ND</i>	<i>P</i>	<i>N</i>	<i>SQ</i>
Mylodon Cave	51°35'S 72°38'W	~11–5.5	31	N-R	34	HRe
Cueva del Medio	51°35'S 72°38'W	~11–2.1	20	N-I	12	MRe-PRe
Don Ariel	52°S 70°09'W	~7–2.6	6	N-R	15	HRe-MRe
Angostura Blanca	42°30'S 70°W	~2.9–2.1	2	R-N	11	HRe-MRe-PRe
A. Circunferencia	22°56'S 65°21'W	~10.7–7.9	5	N-I	36	HRe-MRe
Puerto Segundo	25°59'S 54°39'W	~7–0.6	*	N-R	17	MRe-PRe
Arroyo Yará	26°S 55°21'W	~7–1	*	N-I	14	HRe-MRe
Barranca Pelada	30°15'S 57°37'W	~6–0.3	*	N-I	34	HRe
San Juan	30°S 57°44'W	~6–0.3	*	N-I	21	HRe
Piedra del Aguila 11	40°02'S 70°00'W	~4.9–1.9	9	N-I	90	HRe-MRe
Las Buitreras	51°44'S 70°10'W	~11–3	4	R-N	40	HRe-MRe

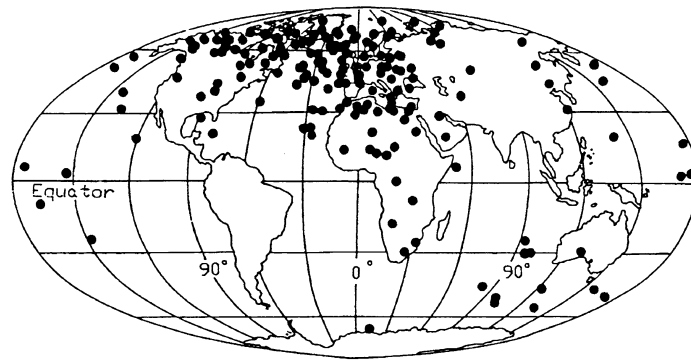


Fig. 16. World map showing the location of the VGP obtained from the sites described in Table 3.

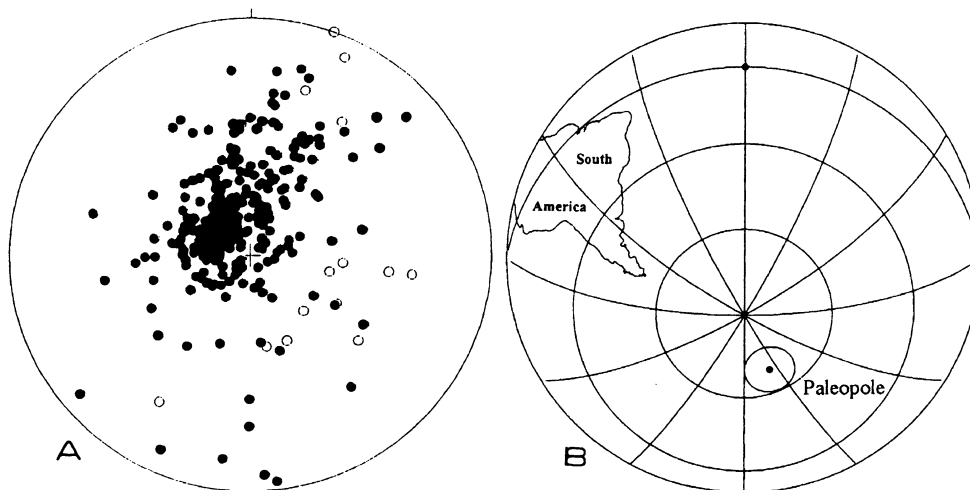


Fig. 17. A) Stereographic projection of the VGP used to isolate the palaeopole showed in B). B) Projection showing the palaeopole obtained with a 40° filter and their confidence interval.

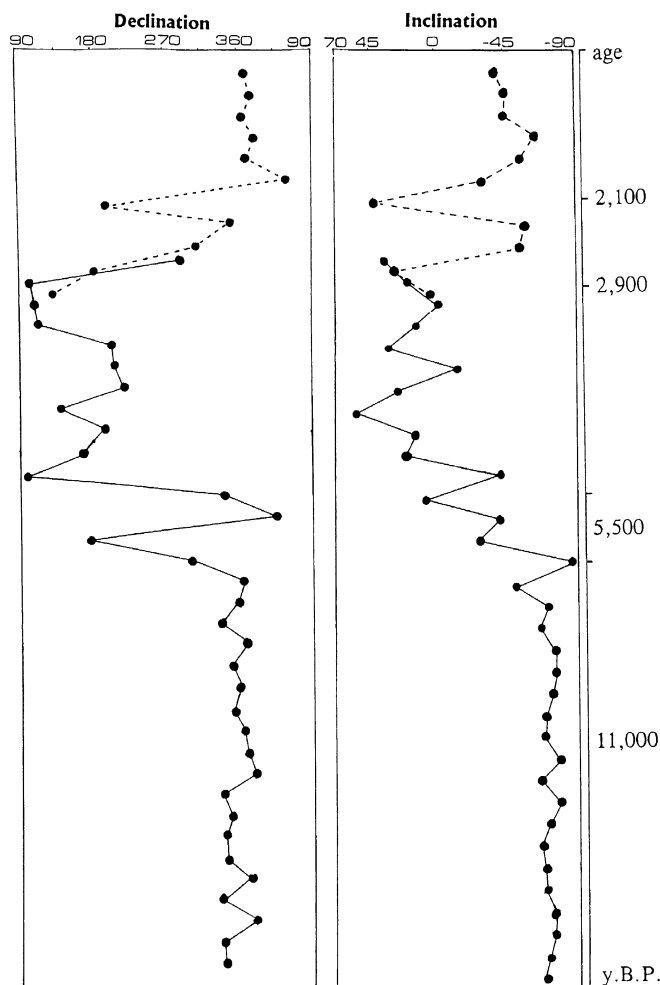


Fig. 18. Plotted declination and inclination from Angostura Blanca rockshelter (dashed line) and Mylodon Cave (continuous line) showing the N-R and R-N geomagnetic field shift between ≤ 11 and ≤ 2 ky bp (from Nami, 1995).

Virtual geomagnetic pole (VGP) positions calculated only from HRe and MRe samples (Fig. 15) coincide remarkably well with transitional VGP's obtained from the sites where the GF anomalous behaviour was observed. It can be seen that they cluster near Antarctica, Australia, Africa, Europe, Eastern Asia and North America (Fig. 16).

In summary, several archaeological and palaeontological sites in southern South America have yielded records of a probable excursion of the Earth's Magnetic Field at sometime in the terminal Pleistocene and Holocene. Alternative interpretations on these records are: they represent the real evidence of the GF direction and the local fluctuations and oscillations occurred during excursions and reversions (Bogue, 1991; Bogue and Merrill, 1992) or, they result from a sediment artefact or, the influence of a delayed remanence acquisition (van Hoof and Langereis, 1991; Langereis *et al.*, 1992, 1997). If this last alternative is true, it is possible to suppose that reversed polarity positions may have existed during that time span.

On-going analysis and putative research will provide additional information on Holocene GF behaviour in southern South America.

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