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Paleomagnetism of the late Cenozoic basalts from northern Patagonia

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Late Cenozoic volcanic rocks outcrop in the northern Patagonia Extrandina. Lava flows, characterized as olivine and alkaline basalts, belong to intraplate volcanism. We report paleomagnetic and rock-magnetic studies carried out on Late Cenozoic basalts belonging to the Cráter, Mojón and Moreniyeu Formations. The paleomagnetic sampling comprised 75 sites in lava flows and dikes from the Cráter Formation, three sites in a lava flow from the Mojón Formation and three sites in a lava flow from the Moreniyeu Formation. Alternating field (AF) and thermal detailed demagnetization techniques were used. Most of the samples have a viscous component. The AF procedure was more effective than thermal demagnetization in destroying viscous components and in defining the characteristic remanent magnetizations. Demagnetization curves and rock-magnetic studies suggest that the main remanence carrier is Ti-poor magnetite. Radiometric K-Ar ages were performed on these basalts. The radiometric ages are 0.8±0.1 Ma from outcrops located at Cerro Fermín and 1.9±0.4 Ma from outcrops at Cerro Negro, both at the Cráter Formation. These ages suggest an early-middle Pleistocene age for the lava flows from Cerro Fermín, and a late Pliocene to early Pleistocene age for the Cerro Negro lava flows. Based on the magnetic polarity temporal scale, the Cerro Fermín lava flows have registered the beginning of the Brunhes Chron, while the Cerro Negro basalts could have been extruded during the Olduvai Subchron. The K-Ar radiometric age of the Moreniyeu Formation (1.6±0.2 Ma) suggests an early Pleistocene age for this lava flow. The reverse polarity of its virtual geomagnetic poles (VGPs) is in agreement with the predominant one during the Matuyama Chron and suggests that the Moreniyeu Formation constitutes another volcanic event clearly separate from those of the Cráter Formation. The K-Ar radiometric age of the Mojón Formation (3.3±0.4 Ma) locates it in the middle Pliocene. The VGP polarity would be correlated with some reverse subchron located in Gauss Chron or with the end of the Gilbert Chron. The petrographical and geochemical similarities between the studied basalt and the Somuncura plateau basalts (late Oligocene-early Miocene, located northern and eastern of the study area), together with the time lapsed among between the Mojón and Cráter basalt extrusion suggest the presence in the area of a temporarily extensive thermal anomalies.

Key words: Paleomagnetism, basalts, Patagonia, late Cenozoic.

1. Introduction

Late Cenozoic volcanic rocks are extended on a huge surface in the northern Patagonia Extrandina. Eruptive centers are aligned following old lines of structural weakness reactivated by the Andean orogeny (Ramos *et al.*, 1982). Lava flows, characterized as olivine and alkaline basalts, belong to intraplate volcanism (Massaferro *et al.*, 2002). Their petrographical and geochemical features suggest a common parental magma, originating from the partial melting of thin and young continental crustals without participation of the subducted plate (Lapido and Pereyra, 1999). The Somuncura Plateau is located to the north and east of these flows, outside of the study area. It is the product of an important late Oligocene-early Miocene volcanism, with a probable origin on a local thermal instability of the mantle or a stationary hot spot (Kay *et al.*, 1993).

Cráter Formation basalts, originally considered to be of Holocene age (Ravazzoli and Sesana, 1977), are constituted of lava flows that fill Quaternary valleys and cover post-glacial sediments (Haller, 2000). These lava flows form a small volcanic field, located in an area centered at latitude 42°S; longitude 70°W (Fig. 1), 300 km to the east of the present Pacific trench (Haller, 2000).

The Mojón Formation, assigned to the late Pleistocene (Ravazzoli and Sesana, 1977), outcrops north of the Crater Formation volcanic field. These volcanic rocks conform to an extensive lava flow located near Mamil Choique, (41°46′S, 70°08′W), Río Negro province. Near Gastre, Chubut province (Fig. 1), another extensive basalt flow is located. These basalts, formally called the Moreniyeu formation, were assigned tentatively to the Early Holocene by Proserpio (1978).

The only other paleomagnetic studies performed on coeval lavas correspond to volcanic rocks exposed 1000 km south of the study area (Brown *et al.*, 2004; Baraldo *et al.*, 2003; Mejia *et al.*, 2004; Singer *et al.*, 2004).

In this contribution, we report a paleomagnetic and rock-magnetic study carried out on basalts belonging to the Cráter, Mojón and Moreniyeu Formations (Fig. 1). These volcanic rocks are relevant as evidence of recent magmatic

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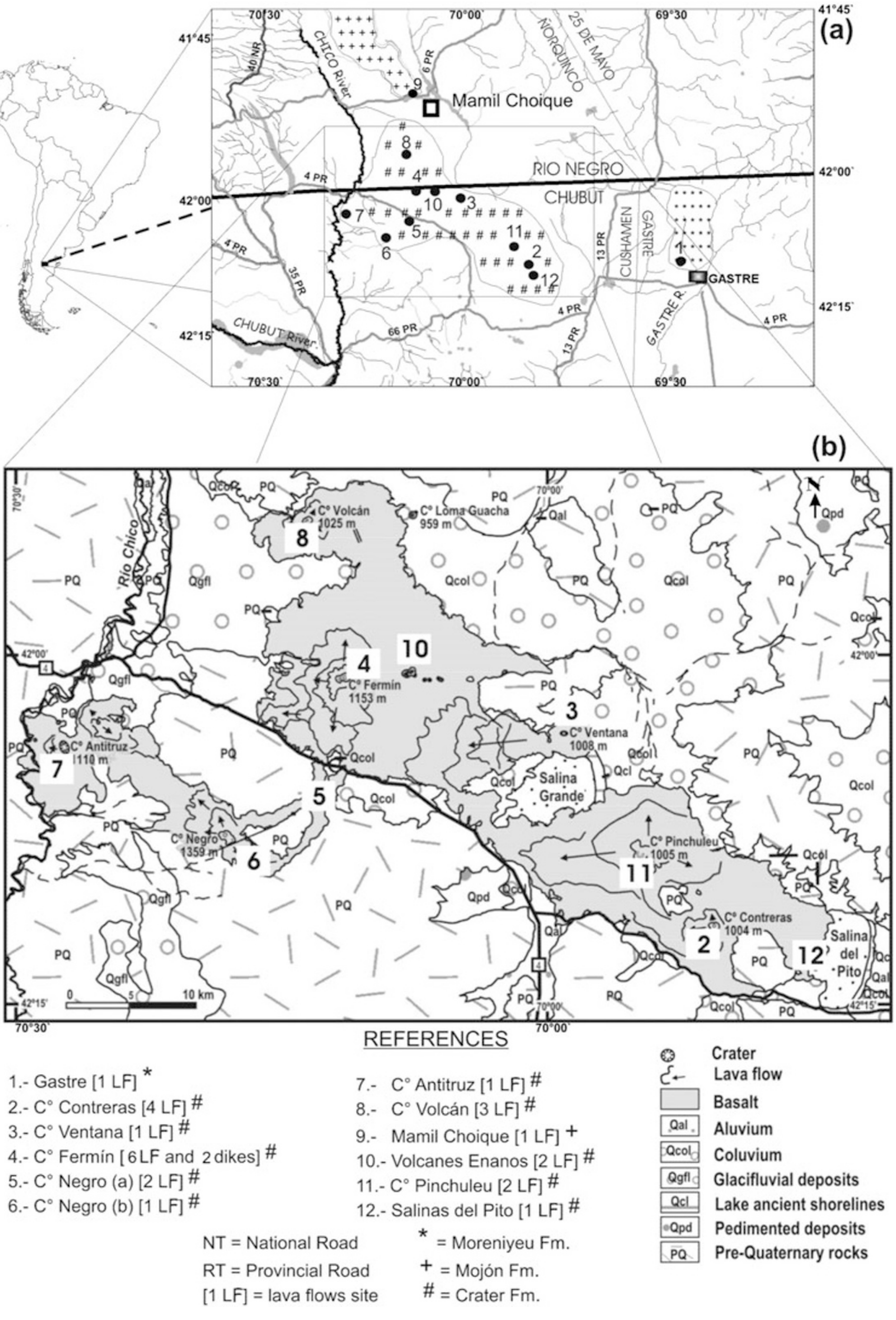

Fig. 1. (a) Sampling localities and sketch location of the Cráter, Mojón and Moreniyeu formations. (b) Cráter Formation outcrops and sampling localities. The numbers of lava flow (LF) or dike (D) sites at each locality are specified in the figure references.

activity in a sector of Patagonia that is considered to be relatively stable from the Tertiary (Masaferro *et al.*, 2002). The establishment of chronological relationships among the different lava flows and the location of their sources are very important for the knowledge of the tectomagmatic activity of the area.

2. Geological Setting

The Cráter Basalt volcanic field covers an area of 257 km^2 and consists of at least nine strombolian centers that erupted basaltic magma above the fluvioglacial terraces. Each vent produced between four and six individual lava flows (Haller *et al.*, 2001). The distribution of the centers is controlled by fractures associated to the Gastre megafracture (Haller, 2004). The Gastre fracture system (Coira *et al.*, 1975) is a NW-SE shear zone, nearly 30 km wide, which has been active since the Triassic; it currently registers shallow seismic activity (Massaferro *et al.*, 2002). At this latitude the Nazca Plate is subducted under the South American Plate at 7 cm/year, with a moderate oblique component (Hervé *et al.*, 2000).

The morphology of the volcanoes is well preserved, with only a few scoria cones that are partially weathered. The thickness of the lava flow varies from 1 to 10 m, and the lava

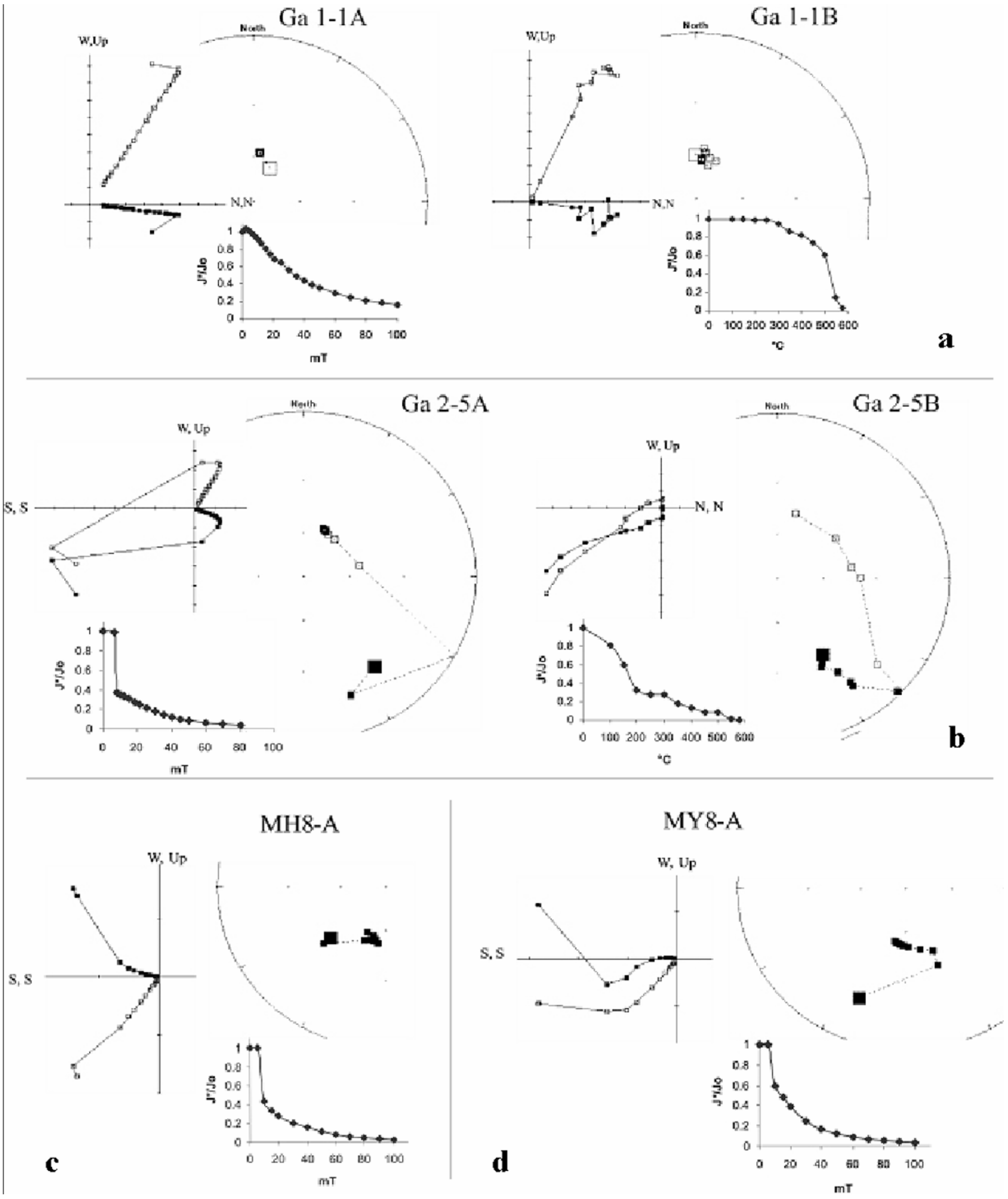

Fig. 2. Orthogonal plots, stereoplots and magnetic intensity curves for demagnetization of representative specimens from: (a) Cráter Formation lava flows at Cerro Negro locality 5, (b) the same as (a), (c) Mojón Formation lava flow at nine localities, (d) Moreniyeu Formation lava flow at one locality. In orthogonal plots, open (solid) squares indicate projection onto the vertical (horizontal) plane. In stereoplots, open (solid) squares indicate projection onto the upper (lower) hemisphere.

flows themselves are mainly of the AA type and, much less, of the pahoehoe type. The outer zones of the lava flows are strongly vesicular in general, although in some cases they have a coarse columnar disjunction. They have been described as black olivinic basalts with porphyritic textures, bearing olivine phenocrysts set in an intergranular to intersertal groundmass (Haller, 2000; Haller *et al.*, 2001; Massaferro *et al.*, 2002). The composition of the groundmass plagioclase laths falls between andesine to labradorite. Nodules with dunitic to lherzolitic composition have been observed (Massaferro *et al.*, 2002). Lavas from different effusive centers have small petrographic differences.

The Cráter Formation has a low weathering degree and overlain late Pleistocene formations. Due to these features its age was considered to be Holocene (Ravazzoli and Sesana, 1977).

The Moreniyeu Formation forms a lava flow that is nearly 12 km long, beginning as an encased flow in a N-S valley and concluding as a flow that is 2 km wide (Proserpio, 1978). In the encased part, the Moreniyeu stream eroded the lava flow in all its thickness. The lava emission center has not been found. Although there are areas of different texture (corded, vesicular, compact), in general the lithology is uniform and very similar to the Cráter Formation basalts. The groundmass with aphanitic textures is constituted of plagioclase, pyroxene prisms and olivine crysts. These basalts were considered by Proserpio (1978) to be of the early Holocene age because of their degree of erosion.

Lava flows of the Mojón Formation flowed into valleys and formed extensive scoria fields that are usually 80–100 m thick. Two vents are located north of these lava flows. Basalts are dense and massive, brown and/or dark in color; they also have irregular fractures. They homogeneous in texture, fine grained, with some olivine crysts. The weathering and erosion grade of these basalts are relatively higher than those of the Cráter basalts (Ravazzoli and Sesana, 1977).

Microscopic observations carried out on polished sections under reflected and transmitted light show similar petrographical features for the basalts of the Mojón, Moreniyeu and Cráter Formation, with the latter being more vesicular and less weathered than the others. Samples from the three basalt formations show a porphyritic texture, with olivine phenocrysts. Maphic minerals are olivine, titanoaugite and opaque. Olivine crystals have an incipient alteration to iddingsite in the borders and fractures. The observed opaque minerals are titanomagnetite and ilmenite, with titanomaghemite and rutile being very scarce. Pyrite and goethite are present in very small quantities. Titanomagnetite is more abundant than ilmenite and generally appears in skeletal crystals. Titanomaghemite appears in small proportions only, as a replacement of titanomagnetite. Goethite is scarce and appears as the centripetal replacement of pyrite. The pyrite appears as a pseudomorphic replace of ilmenite.

3. Paleomagnetic Study

This paleomagnetic study was carried out on samples collected in outcrops of the Cráter, Mojón and Moreniyeu Formations. For each lava flow or dike, three sites were chosen, with three hand samples collected at each one. A denser sampling was carried out at three sites: two located on the oldest lava flow on Cerro Negro and the other one on Cerro Antitruz. At these sites, 16 samples of each site were drilled using a gasoline-powered drill. Sample orientation was performed by both magnetic and solar compasses, whenever possible.

To analyze the remanent magnetization stabilities, three specimens for each hand sample were drilled. Two of these were subjected to alternating fields (AF), while the third was subjected thermal demagnetization procedures. Two specimens were cut from each drilled sample, one to apply AF and another for thermal demagnetization. Remanent magnetization measurements and demagnetizations were made using a 2G cryogenic magnetometer and a Schonstedt furnace.

3.1 Cráter Formation

Paleomagnetic studies were performed on samples collected on 23 lava flows and two dikes. Eight effusive centers belonging to the Cráter Formation in the Sierra del Medio area are the source of these basalts (Fig. 1(a) and (b)).

AF demagnetization was carried out in 5- and 10-mT steps, up to a 100-mT peak demagnetization field. Thermal demagnetization was performed from 100°C up to 550°C, in 50°C steps, with two final steps of 580°C and 600°C. Possible mineralogical changes were controlled by measuring the susceptibility after each step. The bulk magnetic susceptibility at room temperature was measured using a Bartington MS2 susceptibility meter. Many specimens were found to carry monocomponent remanences (59%). There is practically no remanence above 580°C, indicating there is no haematite as magnetic carrier. Some specimens were determined to present a soft viscous remanence of low intensity and very scattered directions. These components are easily removed with 5- to 10-mT AF or less than 300°C (Fig. 2(a)). The dikes from Cerro Fermín (Fig. 1(b)) carry a positive inclination secondary component (SC). These SCs are removed at 12 mT or less and between 250 and 400°C. Using principal component analysis (PCA; Kirschvink, 1980), SC directions were defined with MAD$<10°$. These components show a scattered distribution (Fig. 3). Some specimens of the Cerro Negro lava flow at site B carry SCs with positive inclinations, which are removable with fields of 10–12 mT and temperatures between 300° and 450°C (Fig. 2(b)). The directions defined with PCA and MAD$<10°$ are different to the SCs of the dikes and they are less scattered (Fig. 3).

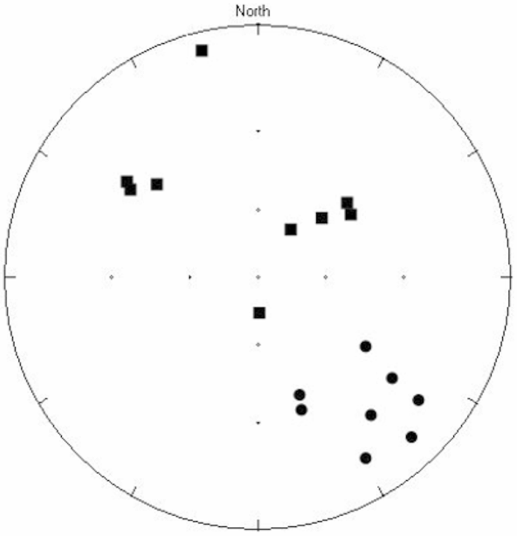

Fig. 3. Secondary component directions of the Fermín dikes (squares) and Cerro Negro (circles) specimens. Solid symbols indicate projection onto the lower hemisphere.

AF procedure was more effective than thermal demagnetization in destroying viscous components and defining the characteristic remanent magnetizations (ChRM). All of the analyzed samples from the Cráter Formation have a ChRM with a negative inclination related to the virtual geomagnetic poles (VGP) with normal polarity. ChRMs were defined using PCA with a MAD$<5°$. Only three specimens subjected to thermal demagnetization have ChRM with a MAD between 5° and 10°.

Six lava flows, in stratigraphic order, were identified at the Cerro Fermín (eruptive center with the highest number of superposed lava flows). For that reason, the ChRM mean directions from Cerro Fermín lava flows were compared with the mean ones from the others sites.

Figure 4(a) shows the ChRM mean directions from Cerro Fermín in stratigraphic order. The comparisons with the other lava flows mean directions are shown in Fig. 4(b)–(e). Inclinations and declinations for all the flows, along

Table 1. Lava flow mean remanence directions and correspondent VGPs for the sampling localities of Cráter Formation. D, I: Declination and inclination for the mean direction; α_{95}: Fisher statistical parameter for this mean; N: number of sites used in the calculation.

Locality	Lava flow	D	I	N	k	α_{95}	VGP Latitude	VGP Longitude
Cerro Fermín	1	5.9	−44.5	9	29.08	9.7	−73.3	128.6
	2	352.7	−45.3	9	57.54	6.8	−73.6	86.3
	3	351.0	−53.2	9	39.59	8.3	−79.1	66.7
	4	14.0	−50.4	9	60.38	6.7	−74.3	159.9
	5	11.9	−51.2	9	161.22	4.1	−76.1	156.7
	6	13.6	−67.8	9	40.79	8.2	−77.3	247.6
Cerro Negro	A	7.3	−59.0	22	60.24	4.0	−84.0	179.3
	B	21.1	−61.1	22	22.47	6.7	−74.4	207.4
	3	9.8	−67.7	9	41.33	8.1	−79.1	254.9
Cerro Antitruz	C	22.1	−59.9	22	32.39	5.5	−73.4	202.6
Cerro Volcán	1	3.1	−51.4	9	28.65	9.8	−79.8	124.8
	2	1.7	−65.1	9	40.32	8.2	−84.7	277.2
	3	278.8	−70.1	9	20.18	11.7	−37.6	336.6
Volcanes Enanos	1	348.6	−65.1	9	26.50	10.2	−80.4	343.7
	2	325.2	−61.7	9	23.26	10.9	−64.5	6.0
Cerro Ventana	1	5.6	−65.7	9	16.27	13.2	−82.9	257.9
Cerro Pinchuleu	1	19.5	−55.9	9	43.41	7.9	−73.9	185.9
	2	8.7	−61.2	9	24.57	10.6	−83.6	204.4
Cerro Contreras	1	323.4	−72.2	9	18.37	12.3	−62.4	334.3
	2	10.6	−60.0	8	37.21	9.2	−82.0	194.4
	3	14.1	−53.7	9	25.42	10.4	−76.4	169.0
	4	16.2	−62.4	9	49.06	7.4	−78.1	213.0
Salina del Pito	1	1.9	−58.9	9	70.15	6.2	−87.1	140.1
Cerro Fermín	1	345.8	−50.6	9	48.65	8.0	−74.4	59.0
Dikes	2	350.2	−31.5	9	17.99	12.5	−63.6	88.6

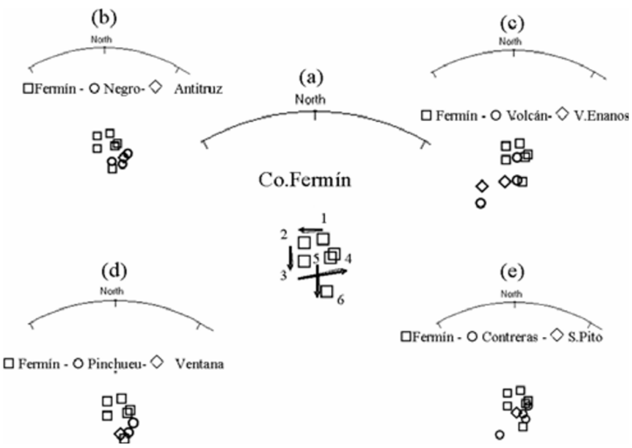

Fig. 4. Mean directions for the six Cerro Fermín lava flows on stratigraphic order (a) and the comparison with lava flows from Cerro Negro and Cerro Antitruz (b), Cerro Volcán and Volcanes Enanos (c), Cerro Pinchuleu and Cerro Ventana (d), Cerro Contreras and Salinas del Pito (e). (Data from Table 1).

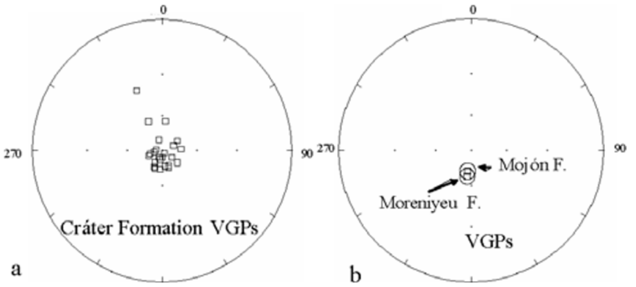

Fig. 5. Southern Hemisphere location for the VGP from (a) Cráter Formation lava flows, (b) Moreniyeu and Mojón Formation lava flows.

with associated statistics and VGPs are given in Table 1. The oldest lava flows of Cerro Negro (locality 5) have mean directions in an intermediate position between the fifth and sixth Cerro Fermín lava flows. The youngest Cerro Negro lava flow (locality 6) has a direction almost coincident with that of the youngest Cerro Fermín lava flow. The mean direction of the Cerro Antitruz lava flow approximates the directions of the youngest lavas from Cerro Fermín and Cerro Negro effusive centers (Fig. 4(b)).

The directions of the two oldest lava flows of the Cerro Volcán sequence are coherent with the three youngest lava flows from Cerro Fermín. The youngest Cerro Volcán flow direction is far from the group (Fig. 4(c)). The direction of the oldest lava flow from Volcanes Enanos is near to that of the youngest Cerro Fermín lava flow, while the youngest Volcanes Enanos lava flow direction moves away from the group (Fig. 4(c)).

The Cerro Ventana lava flow direction is almost coincident with the youngest one of Cerro Fermín (Fig. 4(d)). The two mean directions of Cerro Pinchileu are located in intermediate positions between the directions of youngest lava flows of the Cerro Fermín (Fig. 4(d)).

The oldest lava flow direction from Cerro Contreras is located far from the Cerro Fermín directions. The other Cerro Contreras flows, as well as that of the Salina del Pito, have directions near those of the third and sixth lava flows from the Cerro Fermín (Fig. 4(e)). Although this comparison of directions cannot be taken as indicative of the relative sequence among lava flows from different effusive centers, a

Table 2. Site mean remanence directions and correspondent VGPs for Mojón and Moreniyeu Formation. D, I: Declination and inclination for the mean direction; α_{95}: Fisher statistical parameter for this mean; n: number of specimens used in the calculation.

Formation	Site	D	I	n	k	α_{95}	VGP latitude	VGP Longitude
Moreniyeu	1	210.1	57.3	9	58.67	6.8	−65.5	193.2
	2	206.8	51.3	9	61.39	6.6	−66.4	183.7
	3	200.6	55.0	9	50.98	7.3	−72.7	184.8
Mojón	1	207.4	57.4	9	16.72	13.0	−68.7	198.9
	2	197.9	56.0	9	130.88	4.5	−75.2	485.2
	3	204.2	54.8	9	51.71	7.2	−71.4	189.1

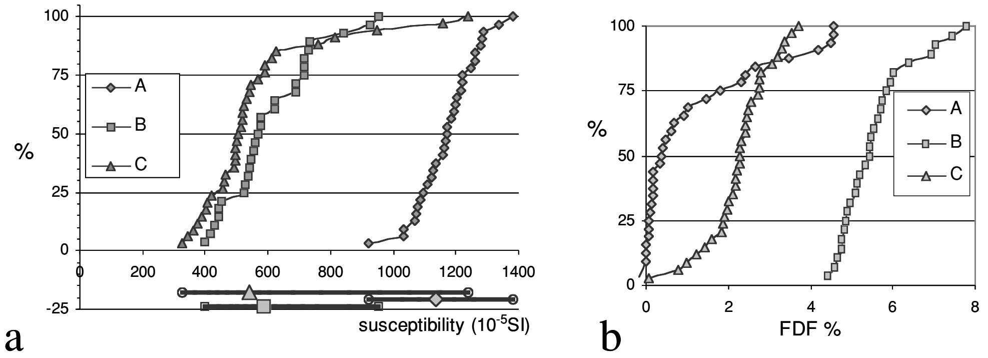

Fig. 6. (a) Cumulative frequency curves of magnetic susceptibility for specimens from sites A, B and C (Cráter Formation). The horizontal bars on the bottom show the values range and the bulk mean susceptibility for each site. (b) Cumulative frequency curves of frequency dependence of susceptibility factors (FDF%) for specimens from sites A, B and C.

detailed chronological sequence of the eruptive events can be described when this information is combined with the radiometric due to the high quality of the paleomagnetic results.

VGPs were calculated from the mean directions. All of these correspond to a normal polarity magnetic field, and they are well grouped. The VGP from the youngest Cerro Volcán lava flow is far away from the group and is located at a lower latitude. The mean VGP is located at latitude 88.6°S, longitude 206.6°E, α_{95}=6.6° (Fig. 5(a)).

3.2 Moreniyeu Formation

The basalts of the Moreniyeu Formation form an extensive lava flow located near Gastre, (Fig. 1(a)). A paleomagnetic study was performed on 27 specimens from three sites of this lava flow.

Most of the specimens show viscous components that were destroyed with fields below 15 mT and temperatures between 350° and 450°C. The directions of these components seem to be random, presenting both positive and negative inclinations (Fig. 2(d)). The ChRMs defined for all of the analyzed specimens have a MAD<10°. These ChRMs have positive inclinations and they are well grouped. The mean directions for the three sites define coincident VGPs of reverse polarity. Inclinations and declinations for the sites, along with associated statistics and VGPs, are given in Table 2. The calculated lava flow VGP is located at a latitude 67.4°S and longitude 189.2°E, α_{95}=6.4° (Fig. 5(b)).

3.3 Mojón Formation

The Mojón Formation constitutes a narrow and long lava flow near Mamil Choique (Fig. 1(a)). Twenty-seven specimens from three sites were analyzed.

Some specimens present viscous components with scattered directions that were destroyed at fields of 15 mT or less. For all of these specimens ChRMs with a positive inclination were defined. ChRMs have a MAD<10° (Fig. 2(c)) and are well grouped. Site mean directions and associated statistics are given in Table 2. The corresponding VGPs have a reverse polarity that is almost coincident between them (Table 2). The Mojón Formation VGP is located at latitude 71.7°S and longitude 190.1°E, α_{95}=6.8°. This VGP is statistically indistinguishable from that of the Moreniyeu Formation VGP (Fig. 5(b)).

4. Magnetic Mineralogy

To identify the minerals that carry the natural remanent magnetization in the Cráter Formation, we performed rock-magnetic studies in specimens from the A and B sites, which are located on the two oldest Cerro Negro lava flows, and from the C site located on Cerro Antitruz.

Bulk magnetic susceptibility at a low and high frequency were measured. Figure 6(a) shows cumulative frequency curves of magnetic susceptibility for all of the specimens of each site. The horizontal bars at the bottom of the figure show the range of values and the bulk mean susceptibility for each site. Site A shows the highest susceptibility values and a more symmetric distribution than sites B and C; it also shows a narrower range, which implies a major quantity of magnetic grains of high susceptibility that are more homogeneous among the samples. This feature would imply a more homogeneous distribution of magnetic minerals in the rock. Sites B and C have similar mean values and skew to the right distributions (Fig. 6(a)), which would imply the existence of concentration zones of magnetic mineral into the flow.

The very fine grain ferromagnetic minerals usually exhibit a frequency dependence of susceptibility, and this

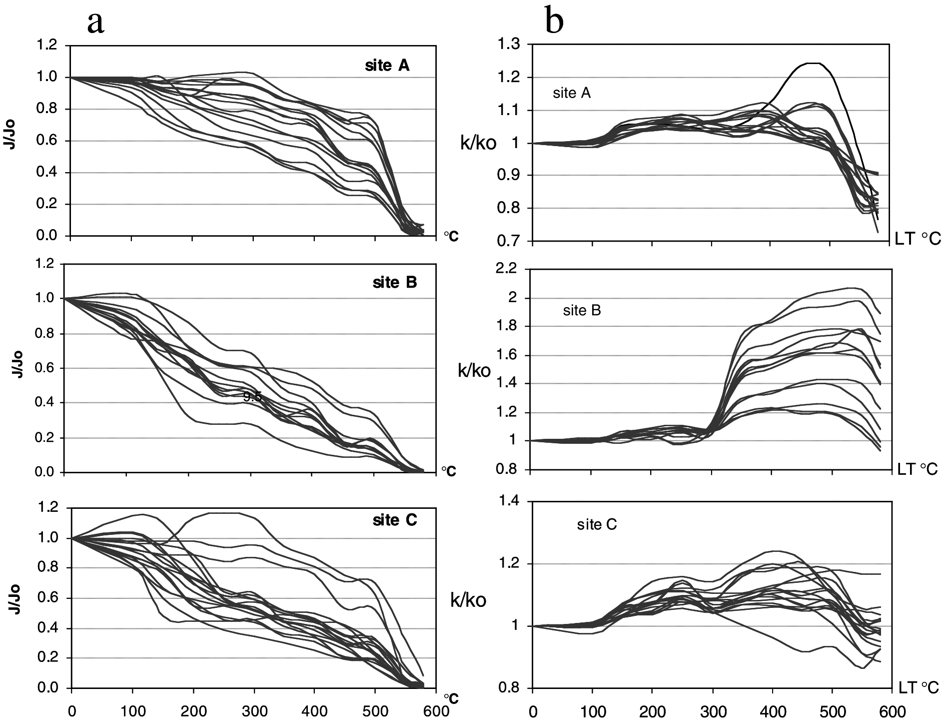

Fig. 7. (a) Normalized thermal demagnetization curves and (b) normalized bulk susceptibility at room temperature (ki/ko) versus heating temperature curves for the specimens from the A, B and C sites (Cráter Formation).

is especially significant when there are superparamagnetic grains (SP). The presence of fine grains is evident by the frequency dependence of the susceptibility factor (FDF). The FDF can be defined as the susceptibility change when the frequency increases by a factor ten, divided by the low frequency susceptibility (Maher and Taylor, 1988; Maher and Thompson, 1991). In the present case, 0.470 kHz and 4.70 kHz were used. FDF distribution shows very low values for sites A and C and higher values for site B (Fig. 6(b)). These distributions could indicate the presence of SP grains at site B.

Thermal demagnetization curves show a wide range of unblocking temperatures (Fig. 7(a)). This can suggest the presence of Ti-poor titanomagnetite with very varied grain sizes because the curve slopes are almost constant during the whole demagnetization process.

All the curves show that the remanence practically disappears when reaching magnetite Curie temperature (approx. 580°C). This behavior indicates the absence of haematite as a magnetic carrier. Furthermore, after each heating-cooling step the bulk magnetic susceptibility at room temperature (ki) was measured. The ki susceptibility versus heating temperature curves clearly show that there are mineralogical differences among the three sites. These susceptibility variations could be correlated with mineralogical changes during the thermal treatment.

The analysis of the ki susceptibility/initial susceptibility (ki/ko) ratios of each step (Fig. 7(b)) suggests that, around 200°C, a mineral that increases the susceptibility appears in specimens from the three sites. Around 350°C, a new susceptibility increase takes place. These behaviors, much more evident for site B, would indicate the formation of a ferromagnetic mineral from a non-ferromagnetic one.

Since these are olivine basalts, and given that olivine is an unstable mineral that can form Fe-oxides at low temperatures, this could be the process responsible for the modifications in susceptibility. The occurrence of this phenomenon at different temperatures could be due to differently sized olivine grains and/or to olivine with preexistent alteration aureoles. As such, the mentioned susceptibility increments could be correlated with the formation of iddingsite rims (determined by microscopic observations) as an alteration product of olivine following the heating of specimens during the thermal demagnetization. The formation of these new minerals does not affect the directional information because the titanomagnetites dominate those properties. These new minerals could be responsible for the noise observed in high-temperature demagnetizations for some specimens. Around 400–500°C the process is inverted, susceptibility falls dramatically, indicating that titanomagnetite oxidation takes place.

5. Discussion and Conclusions

These basalts are an excellent recorders of the paleodirection of the geomagnetic field during the extrusion moment due to their magnetic characteristics. On the other hand, preliminary studies of magnetic fabric performed on these lava flows show that both the susceptibilities and anisotropy of the magnetic susceptibility (AMS) are controlled by titanomagnetites (Singer *et al.*, 2005). Proximal and mesial lava flow sections show a larger scatter of the principal susceptibility axes related to distortions of the flow caused by degassing. Samples from the intermediate levels of the distal sections, with few vesicles, show more consistent magnetic fabrics. These sites have oblate fabrics with well-defined magnetic foliation planes tilting downflow, reflecting the flow advance while the minimum principal axes plunge sourceward (Singer *et al.*, 2005).

Based on geologic and geomorphologic relations, the Cráter and Moreniyeu Formations were assigned to Holocene (Ravazzoli and Sesana, 1977; Proserpio, 1978); for similar reasons the Mojón Formation was assigned to the late Pleistocene (Ravazzoli and Sesana, 1977). Radiometric K-Ar ages performed on these basalts are the following: 0.8±0.1 Ma from outcrops of the Cráter Formation located at Cerro Fermín; 1.9±0.4 Ma from outcrops of the Cráter Formation at Cerro Negro; 1.6±0.2 Ma for a lava flow from Moreniyeu Formation and 3.3±0.4 Ma for a lava flow from the Mojón Formation (Mena *et al.*, 2005).

These radiometric ages allow us to discard the proposed Holocene age for the Cráter Formation and to assign an early-middle Pleistocene age for the lava flows from Cerro Fermín and a late Pliocene to early Pleistocene age for the lava flows from Cerro Negro. The discrepancy in the Cerro Fermín (0.8±0.1 Ma) and Cerro Negro (1.9±0.4 Ma) radiometric ages distinguishes at least two different units in the Cráter Formation. According to the magnetic polarity temporal scale (MPS; Cande and Kent, 1995) and the normal polarity of the Cráter Formation VGPs, the Cerro Fermín lava flows have registered the beginning of the Brunhes Chron, while the Cerro Negro basalts could have been extruded during the Olduvai Subchron.

In addition, we discard the Holocene age for the Moreniyeu Formation and suggest an early Pleistocene age. Keeping in mind the radiometric age (1.6±0.2 Ma) and the reverse polarity of its VGPs, the Moreniyeu Formation constitutes another volcanic event that clearly separates it from the Cráter Formation volcanic events. This polarity is in agreement with the predominant polarity during the Matuyama Chron.

On the other hand, the radiometric age of the Mojón Formation radiometric age (3.3±0.4 Ma) locates it in the middle Pliocene. As such, the reverse polarity of its VGPs would be correlated with some reverse subchron located in the Gauss Chron or with the end of the Gilbert Chron.

Secondary remanences corresponding to reverse polarities recorded in rocks from Cráter Formation dikes at Cerro Fermín are particularly interesting. This overprint could be correlated with the Blake event, or with some of the geomagnetic events registered in the Brunhes Chron (Langerais *et al.*, 1997; Lund *et al.*, 1998).

The considerable time spans among the radiometric ages of the lava flows for the three studied formations indicate a long-lived volcanic activity in the area. The Somuncura Plateau is located to the north and east of these flows, outside of the study area. This basaltic plateau is the product of an important late Oligocene-early Miocene volcanism, with a probable origin on a local thermal instability of the mantle or a stationary hot spot (Kay *et al.*, 1993). Considering the similar geochemical characteristics and comparable geological settings shown for the Cráter basalt and the Somuncura plateau basalts, Haller and Massaferro (2005) proposed for both an akin origin by mantle diapirs, but of a lesser extent and duration for the first. These petrographical and geochemical similarities together with the time lapsed between the Mojón and Cráter basalt extrusion suggest the presence in the area of temporarily extensive thermal anomalies.

Magnetic characteristics of the basalts of the Cráter, Moreniyeu and Mojón Formations are appropriate for detailed paleomagnetic and AMS studies. These types of studies, together with new geochronologic data. could contribute to our knowledge of the episodes that originated these volcanic rocks and help determine flow directions and emplacement conditions, establish the possible correlation among different lava flows, define their relative and absolute ages and establish the intervals lapsed between the different volcanic pulses.

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