Post-magmatic sedimentation in the Paraná Basin, Brazil: paleomagnetic constraints on the age of the Cretaceous Caiuá Group

Sedimentación post-magmática en la cuenca del Paraná, Brasil: Aproximaciones paleomagnéticas de la edad del Grupo Caiuá, del Cretácico

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ABSTRACT

The Caiuá and Bauru Groups of Cretaceous age, represent the post-volcanic sedimentation in the Paraná Basin. Under dry conditions, extensive dunes (Draa) were formed with depocenter in the southern area. Later, under more humid conditions, the fluvial-aeolian processes reworked the dunes, forming a landscape with small dunes and river channels. The Caiuá Group comprises, in ascending stratigraphic order, the Goio Erê Formation (margins of Draa), the Rio Paraná Formation (inner Draa) and the Santo Anastácio Formation (Paleosols). Paleomagnetic results from five sections of the Caiuá Group (Rio Paraná and Santo Anastácio formations) revealed that these rocks carry remanent magnetization due primarily to magnetite and smaller contents of hematite. A paleomagnetic pole at 87.4 ºS 56.6 ºE (N=29, A_{95}=6.5°, k=18) for the Caiuá Group plots close to the poles from the dyke swarms (Ponta Grossa, Florianópolis and the alkaline dykes from Paraguay) of ages 134-127 Ma, indicating that the sedimentation of the Caiuá Group was restricted to the Lower Cretaceous. Furthermore, as part of the rocks were magnetized under transitional and reversed fields, the upper age limit is probably 120 Ma, the initiation of the Cretaceous Normal Superchron, and therefore not younger than the Barremian age.

Keywords: Caiuá Group, paleomagnetism, Paraná Basin, Cretaceous.

RESUMEN

Los Grupos Caiuá y Bauru del periodo Cretácico, representan la sedimentación post volcánica de la Cuenca del Paraná. En condiciones secas se formaron extensas dunas (Draa) con depocentro en la zona sur. Posteriormente, en condiciones más húmedas, los procesos fluviales-eólicos reelaboraron las dunas formando un paisaje con pequeñas dunas y cauces fluviales. El Grupo Caiuá comprende, en orden estratigráfico ascendente, la Formación Goio Erê (márgenes del Draa), la Formación Río Paraná (interior del Draa) y la Formación Santo Anastácio (Paleosoles). Los resultados paleomagnéticos de cinco secciones del Grupo Caiuá (formaciones Río Paraná y Santo Anastácio) revelaron que estas rocas tienen magnetización remanente debido principalmente a magnetita y menores contenidos de hematita. El polo paleomagnético a 87.4 ºS 56.6 ºE (N=29, A95=6.5°, k=18) para el Grupo Caiuá se acerca de los polos de los enjambres de diques (Ponta Grossa, Florianópolis y los diques alcalinos de Paraguay) de edades 134-127 Ma, lo que indica que la sedimentación del Grupo Caiuá estuvo restringida al Cretácico Inferior. Además, como parte de las rocas fueron magnetizadas bajo campos magnéticos de transición o reversos, el límite de edad superior es probablemente 120 Ma, el inicio del Supercrono Normal del Cretácico y, por lo tanto, no es más joven que la edad Barremiana.

Palabras clave: Grupo Caiuá, paleomagnetismo, Cuenca del Paraná, Cretácico.

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1. Introduction

The volcanic activity in the Paraná Basin (Figure 1) occurred in the Lower Cretaceous, and its main phase covered a short time interval from 135 to 133 Ma (Janasi *et al.*, 2011; Thiede and Vasconcelos, 2010). It formed the large Paraná Magmatic Province (Bologna *et al.*, 2022), which preceded the South Atlantic opening. The tectonic processes associated with the breakup of the former Western Gondwana plate created conditions for forming a new sedimentary basin, mainly in the northwestern portion of the province (Fernandes, 1988). The first deposits were of an aeolian-fluvial nature (Caiuá Group) that filled the irregularities of the basaltic surface, corresponding to the Goio-Erê, Rio Paraná, and Santo Anastácio formations (Fernandes and Coimbra, 1994; Fernandes and Coimbra, 2000; Silva *et al.*, 2009). Those units crop out mainly along the Paraná River, comprising the western part of the Paraná and São Paulo states and the eastern Mato Grosso state (Figure 1). A second depositional phase occurred under more humid conditions, with its depocenter displaced to the north, corresponding to the Bauru Group (Araçatuba, Adamantina, Uberaba, and Marília formations) (Batezelli, 2017). Fernandes and Coimbra (1994; 2000) proposed a unique sedimentary basin (Bauru Basin) containing the two groups as they may appear interfingered. However, since Fulfaro and Barcelos (1993), two groups with distinct ages have generally been admitted based on stratigraphic analyses.

The age of the Caiuá Group marks the initiation of post-magmatic sedimentation but is still under debate. Soares *et al.* (1980) proposed an Aptian age to the Caiuá Group. Dias-Brito *et al.* (2001) also estimated an Aptian-Cenomanian age for the Caiuá sediments, whereas Fernandes and Coimbra (1994) considered that the Bauru Basin formed during the Late Cretaceous. A paleomagnetic work on those rocks may help better constrain the age of those sediments and their relationship with the tectonic evolution of the basin.

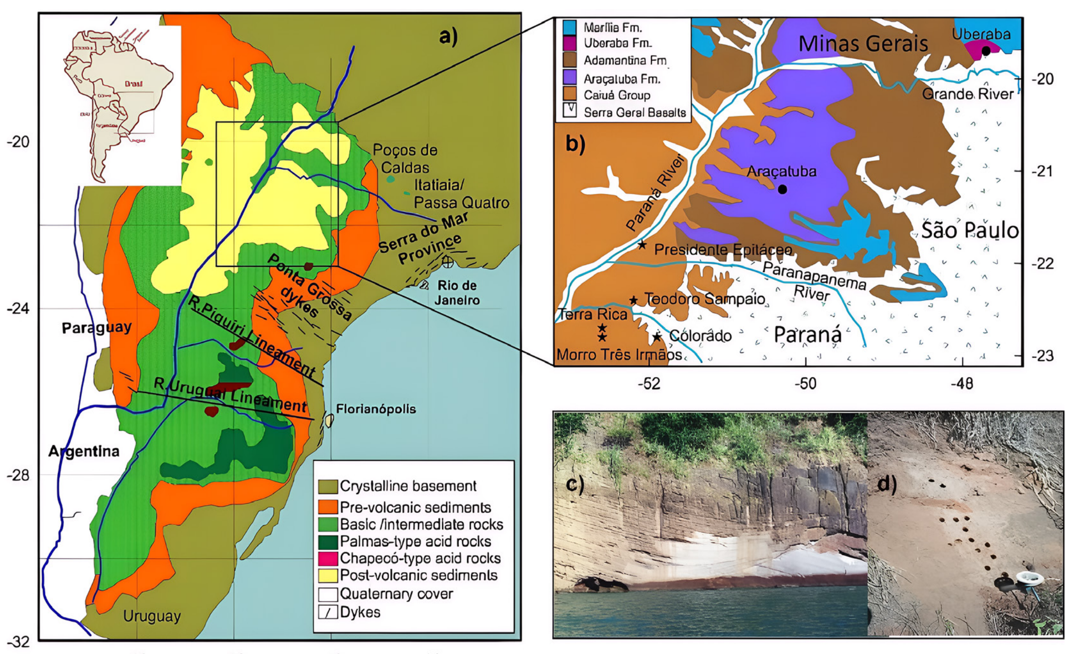

Figure 1 a) A Paraná Basin map showing the occurrence of the Serra Geral volcanics, dyke swarms and the Bauru/Caiuá Basin. b) The Bauru/Caiuá Basin (Batezelli, 2017) and the location of the sampling localities (black stars). c) Outcrop of the Rio Paraná and d) the Santo Anastácio formations.

Table 1. Description of sampling localities.

Formation	Section	Latitude (°S)	Longitude (°W)	Elevation (m)/ sampled thickness (m)	Number of cylinders/blocks
Rio Paraná	Paraná	21.7427	52.0868	272/11	25/5
Rio Paraná	Colorado	22.8238	51.9506	420/8	9
Rio Paraná	Terra Rica	22.6865	52.5600	420/7	34/3
Rio Paraná	Morro Três Irmãos	22.7827	52.6504	613/6	23
Santo Anastácio	Presidente Venceslau	22.0494	51.8999	377/5	28

2. Geological aspects

The Caiuá sedimentation occurred unconformably over the Paraná basalts (Batezelli, 2010; Batezelli, 2017; Fernandes and Coimbra, 1994), occupying the depression developed by thermal subsidence along the central-north area of the Paraná Basin (Figure 1), from the northern Paraná State to southern Minas Gerais State. Under arid climate conditions, giant wind dunes (Draa) formed in the central part of the desert, and peripheral dunes were possibly influenced by ephemeral floods (Batezelli, 2010). The Caiuá Group occupies an area of 2,222 km² along the Paraná River in the west of the States of São Paulo and northern Paraná, eastern of Mato Grosso do Sul and south of the Minas Gerais State (Batezelli, 2010; Batezelli, 2017; Fernandes and Coimbra, 1994). Its depocenter is in the Paraná State, where the sediments may reach a thickness of 280m (Fernandes and Ribeiro, 2015). In ascending stratigraphic order, with major depositional environments in parentheses, the Group is composed of the Goio Erê Formation (margins of Draa), the Rio Paraná Formation (inner Draa), and the Santo Anastácio Formation (Paleosols).

According to Fernandes and Coimbra (2000), the Goio Erê Formation consists of quartz and sub-arkose sandstones, reddish-brown to purplish-grey, fine- to very fine-grained, and occasionally medium-grained. The tabular strata present cross-stratification and are interspersed with massive metric sandstone layers. The cross-stratification, of medium to small size (up to three meters in height), is of the channeled or tangential tabular type at the base, respectively, in a section perpendicular or parallel to the direction of the paleo flow. This unit corresponds to deposits in peripheral sand sea areas, where there were no conditions for accumulating and preserving large wind farms. The subhorizontal sandy strata with channeled cross-stratifications are attributed to moderately sized barchan dune deposits.

The Rio Paraná Formation is made of brown-reddish fine-to-medium grain sandstones containing about 17% silt and clay that originated during the diagenesis (Fernandes and Coimbra, 1994; Fernandes and Ribeiro, 2015; Milani *et al.*, 2007). The unit exhibits well-developed cross-stratification, indicating an arid depositional environment favoring the building of wind dunes of significant size. The Rio Paraná Formation gradually changed into the Goio Erê and Santo Anastácio formations. The cross-stratifications become less defined, indicating the transition from a desertic condition to a lacustrine sedimentation. In some areas of the basin, the Santo Anastácio Formation occurs at the top of the Caiuá Group (Figure 1), displaying a well-selected, massive sandstone. On the top, the Santo Anastácio Formation may reach 100 m of fine-grained and massive sandstones. This unit has been interpreted as a paleosol on the top of the Caiuá Group (Batezelli, 2010; Batezelli, 2017; Fulfaro *et al.*, 1999).

3. Experimental work

Four sections of the Rio Paraná Formation and one of the Santo Anastácio Formation were sam-

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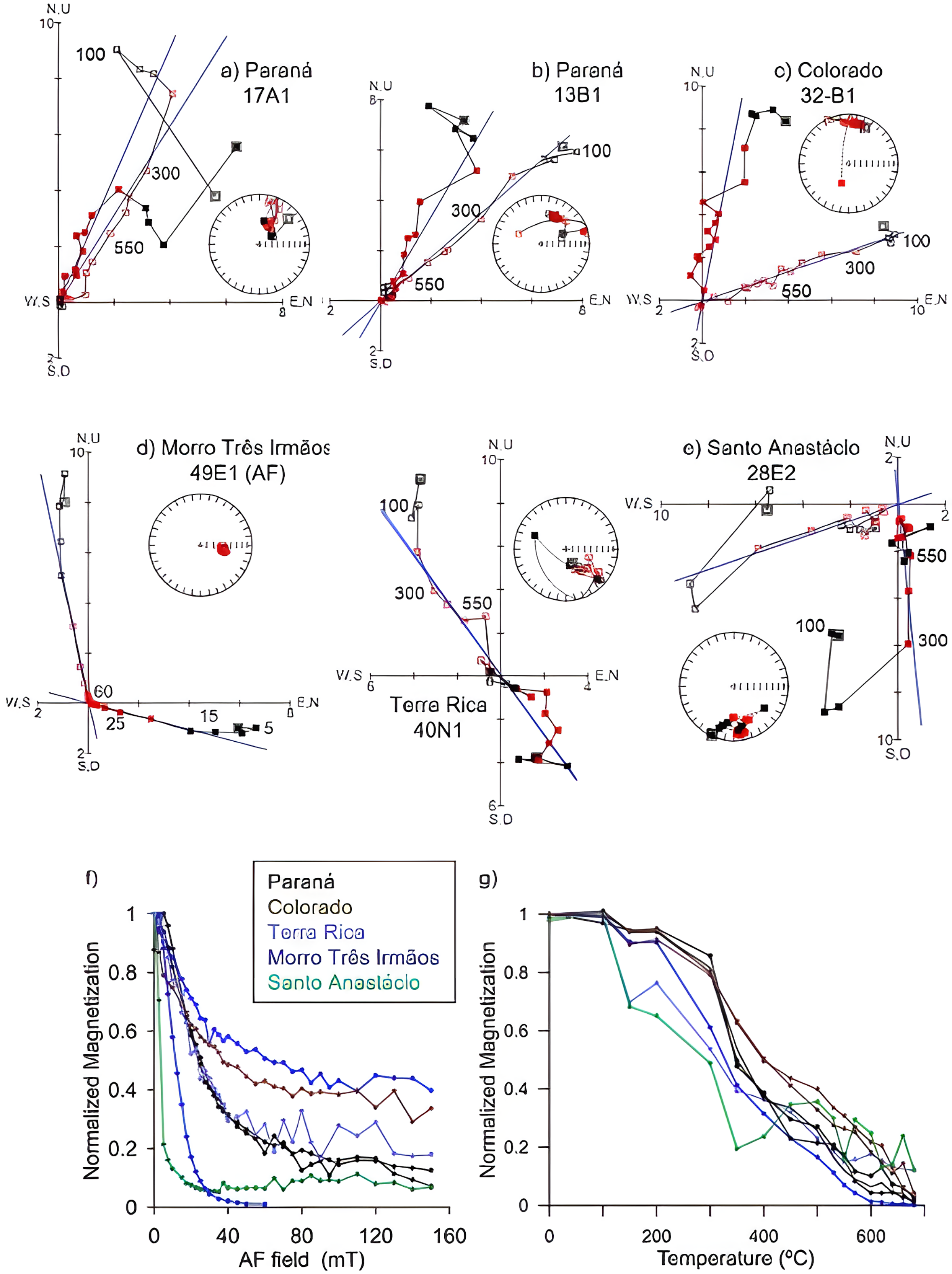

Figure 2 Orthogonal plots (a to e) of the remanence vector during demagnetization using the Puffinplot software (Lurcock and Florindo, 2019). All diagrams refer to thermal demagnetization, except the one for the Morro Três Irmãos section (d), which is AF. Red points are the selected points to calculate the magnetization component. Blue lines best fit the segments using the principal component analysis.

pled for the paleomagnetic work. The Rio Paraná Formation was best sampled in four sections (Figure 1; Table 1). Oriented cores were taken with a gasoline-powered drill whenever possible. Alternatively, some oriented hand-blocks were cut from the friable outcrops. For the experimental work, samples were prepared into standard specimens (2.5 cm diameter and 2.2 cm long). On the left bank of the Paraná River at the city of Presidente Epitácio (SP), a good exposure of the aeolic sediments allowed a denser sampling. This section is hereafter called the Paraná section.

Some samples from each section were selected to test the alternating field (AF) demagnetization efficiency. AF cleaning was performed up to 100 mT (generally, steps of 5 mT) in a Molspin tumbler demagnetizer. Still, better results were obtained with thermal demagnetization up to 680 ºC, starting at 150 ºC and increasing temperature with steps of 50 ºC). Remanences were measured in JR6 spinner and 2G cryogenic magnetometers, and samples were stored inside a magnetically shielded room in the Laboratory of Paleomagnetism, University of São Paulo, Brazil.

However, about 60% of the analyzed samples yielded no reliable results as their characteristic remanence magnetization could not be appropriately determined. The magnetic remanence became very noisy after some steps of demagnetization. The magnetic components were identified and calculated using the Remasoft/Agico software by principal component analysis (Kirschvink, 1980) for good demagnetization results. Examples of the AF and thermal demagnetization results are displayed in Figure 2.

Table 2 and Figure 3a displays the most stable magnetization components. All sections are horizontal/subhorizontal, and no tectonic correction was applied. They were selected considering only results with a maximum angular deviation (MAD) of less than 15°. Normal and reversed polarity components and many anomalous or intermediate directions were identified. The Rio Paraná (except site 25) and Colorado sections yielded only

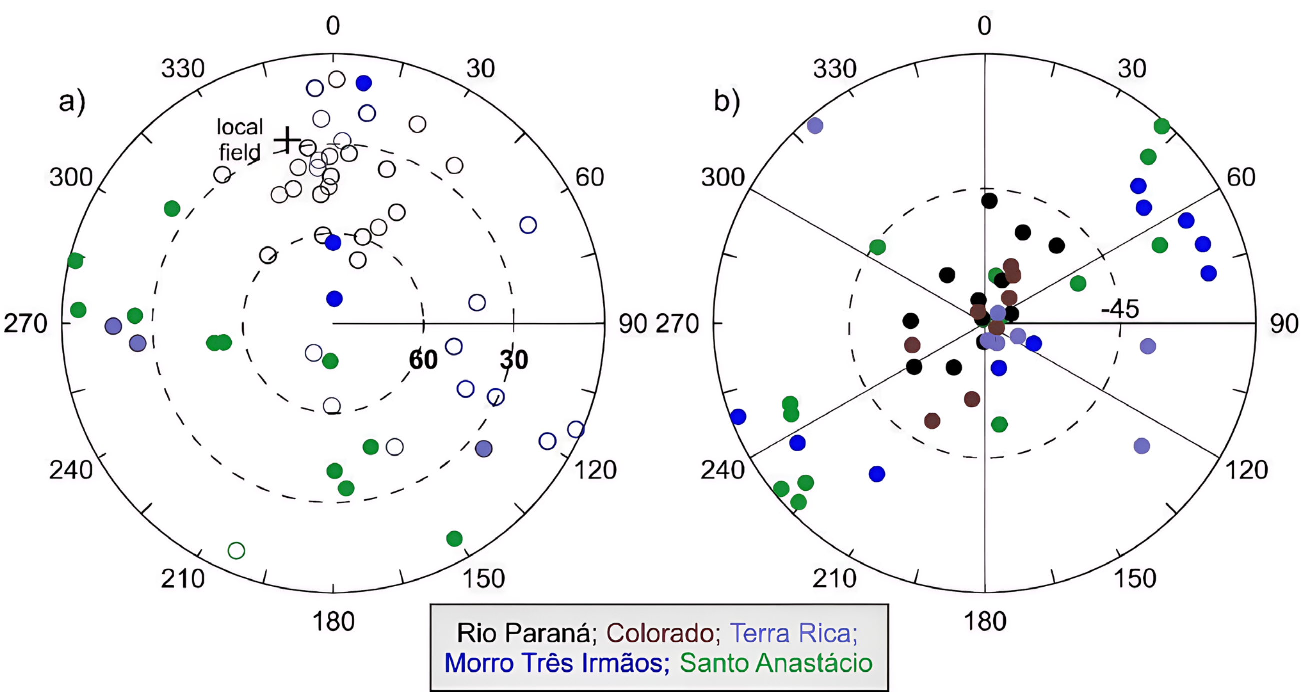

Figure 3 a) Characteristic remanent magnetizations with MAD < 15º for the Caiuá Group. Open (full) symbols represent negative (positive) magnetic inclinations. Colors indicate results by formation. b) South virtual geomagnetic poles represented by the same colors as in a).

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Table 2. Paleomagnetic results for the cylinders from the Caiuá and Santo Anastácio formation showing the sample relative position (Elev), magnetization declinations and inclination (Dec and Inc), number of demagnetization steps (N) for the component calculation and the maximum angular deviation (MAD), and the coordinates (VGP-Long an VGP-Lat) of the corresponding VGPs.

Section	Sample	Elev (m)	Dec (°)	Inc (°)	N	MAD (°)	VGP-Long (°S)	VGP-Lat (°S)
Rio Paraná Formation								
Colorado	29A1	0.0	358.1	-44.4	5	3.1	330.9	-85.6
Colorado	30A2	0.23	347.5	-36.7	6	12.7	43.7	-78.2
Colorado	30D1	0.25	358.8	-34.2	10	9.5	112.4	-85.8
Colorado	31A2	0.68	337.4	-43.5	5	9.0	24.5	-69.1
Colorado	32B1	1.03	22.8	-17.8	15	8.5	189.6	-64.2
Colorado	34E1	2.72	25.2	-54.6	14	9.7	253.0	-64.9
Colorado	37B1[1]	4.7	37.4	-23.7	9	6.0	208.2	-52.9
Colorado	37C1	4.75	0.8	-8.5	8	8.0	30.6	-71.4
Morro Três Irmãos	43B2[1]	7.38	119.0	-8.7	13	5.3	53.8	-24.6
Morro Três Irmãos	42C1	7.18	9.1	-19.0	8	3.6	162.6	-74.3
Morro Três Irmãos	43E1[1]	5.55	301.9	47.7	12	3.4	77.3	-13.9
Morro Três Irmãos	43I1	4.60	355.6	-11.3	5	1.5	112.7	-72.4
Morro Três Irmãos	49C1[1]	3.50	101.0	-49.2	10	2.5	249.1	-2.4
Morro Três Irmãos	44C1[1]	3.0	81.8	-41.8	7	13.5	237.2	-16.2
Morro Três Irmãos	51A2[1]	1.7	113.8	-2.0	10	5.0	48.0	-21.4
Morro Três Irmãos	51C2[1]	1.5	114.5	-30.7	10	4.1	62.9	-14.9
Morro Três Irmãos	51F3[1]	1.3	116.5	-40.9	5	7.1	69.9	-12.9
Morro Três Irmãos	52A1[1]	0.00	63.1	-17.5	7	9.0	215.4	-28.2
Paraná	25B1[1]	9.10	117.1	-29.9	6	10.1	64.0	-17.7
Paraná	25D2[1]	9.00	316.4	-58.7	5	14.9	2.2	-49.1
Paraná	22B1	7.60	353.4	-60.4	8	6.4	322.3	-69.6
Paraná	21B1	7.00	5.3	-33.1	5	5.8	182.3	-83.8
Paraná	23C1[1]	3.55	351.8	-30.8	7	6.0	70.1	-80.7
Paraná	18C1	5.00	323.5	-28.2	7	2.3	42.6	-54.8
Paraná	18B1	4.95	354.5	-46.8	17	4.5	345.2	-82.0
Paraná	18F1	4.90	343.6	-43.2	7	7.3	21.9	-74.6
Paraná	17A1	4.20	29.6	-47.4	9	7.3	238.2	-62.4
Paraná	13B1	2.15	19.1	-35.6	12	6.0	214.8	-72.0
Paraná	13C2	2.10	21.2	-67.3	8	8.5	22.6	-57.1
Paraná	7A1	1.00	18.8	-59.6	8	5.5	271.8	-65.4
Paraná	7C1	0.80	359.1	-40.9	9	0.9	334.1	-88.1
Terra Rica	40C2[1]	1.42	212.9	-78.2	9	13.4	319.6	-3.3
Terra Rica	40F2	1.6	2.9	-29.0	4	6.9	148.8	-82.3
Terra Rica	40J1	1.9	354.3	-37.8	7	9.7	52.1	-84.5
Terra Rica	40N1	2.6	153.7	-43.9	7	10.5	98.1	-35.3
Terra Rica	41E2	4.2	355.0	-35.3	6	7.4	170.9	-84.3
Terra Rica	38L3	6.7	256.7	-21.6	7	8.4	111.6	-78.1
Santo Anastácio Formation								
Presidente Venceslau	28G11	3.20	305.6	24.2	4	8.2	65.8	-26.4
Presidente Venceslau	28E2	2.90	175.5	34.7	4	4.6	72.3	-84.9
Presidente Venceslau	27M1	2.00	202.9	-7.5	5	6.1	171.8	-55.8
Presidente Venceslau	27K1	1.80	179.4	40.6	4	7.7	333.7	-88.7
Presidente Venceslau	27J1[1]	1.62	260.0	53.1	6	8.7	247.3	-20.0
Presidente Venceslau	27I1[1]	1.52	260.5	50.1	12	14.2	244.6	-18.9
Presidente Venceslau	27H1	1.40	163.2	46.8	16	14.1	13.2	-73.7
Presidente Venceslau	27G1[1]	1.20	272.2	24.2	8	12.4	230.7	-2.7
Presidente Venceslau	27D1[1]	1.00	184.1	77.3	7	8.2	30.7	-46.2
Presidente Venceslau	27B1[1]	0.85	283.7	2.0	8	12.6	44.3	-12.3
Presidente Venceslau	27A2	0.65	150.8	7.5	9	11.7	66.8	-56.3
Presidente Venceslau	26F1[1]	0.60	273.0	5.4	7	10.2	41.7	-1.8
Presidente Venceslau	26C1[1]	0.20	264.1	24.8	8	6.6	228.1	-10.2
Presidente Venceslau	26B1[1]	0.15	269.2	17.1	11	5.7	229.9	-4.01
Presidente Venceslau	26A1[1]	0.0	130.0	24.8	8	9.1	10.1	-41.7

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normal polarity directions, which are well grouped and are distinct from the local geomagnetic field. The other sections showed transitional directions. Still, only the Santo Anastácio samples recorded directions compatible with a reversed field. These sites have inclinations >30º and are opposite to the mean inclination of the significant group of normal components. The corresponding virtual geomagnetic poles (VGPs; Figure 3b) represented as south poles are mostly confined inside the 45º polar cap, and a second group plots at latitudes < 30º and longitudes of ~60 and 240 ºE. These results correspond to the Morro Três Irmãos and Santo Anastácio sections. The Terra Rica section also displays transitional (or anomalous) VGPs at different longitudes.

All results were obtained by thermal demagnetization, although AF cleaning gave reliable results in some cases (Figure 4). The VGP latitude variations versus the relative stratigraphic elevations show consistency between the AF and thermal cleanings, although the AF is generally more scattered. The general tendency is preserved in all sections except the Colorado section. This observation is vital as thermal cleaning could eventually impart some spurious magnetization to the samples during mineralogical alterations. This behavior could be true in the Santo Anastácio section, where the thermal demagnetization seems noisy, but the thermal and AF cleaning indicated mainly low latitude VGPs.

3.1. MAGNETIC MINERALOGY

The thermomagnetic curves (susceptibility vs. temperature) for samples from the studied outcrops are noisy as the initial susceptibility is generally low. Most curves indicate Curie temperatures near 600ºC or higher. The AF and thermal demagnetization curves indicated that a considerable part of the remanence could be eliminated at low AF fields. Still, the higher fields were insufficient to completely erase the magnetizations in many cases. Therefore, mixed soft and high-coercivity minerals must carry the magnetization. During thermal demagnetization, ca. 80% of the total remanence intensity was preserved at temperatures higher than 150 ºC, discarding goethite's presence. The isothermal remnant magnetization (IRM) curves (Figure 5) show that magnetization saturation generally occurred at fields higher than 2,000 mT, indicating the presence of high coercivity minerals such as hematite.

Inspecting the magnetic mineral assemblages using the IRM-Unmix protocols (Maxbauer *et al.*, 2016) revealed complex mineral assemblages. Some examples for the Paraná and Colorado sections in Figure 5 show the adjustment of the two main coercivity components. These components generally range from 30-40 mT to 40-55 mT, indicating magnetite is in the lower range.

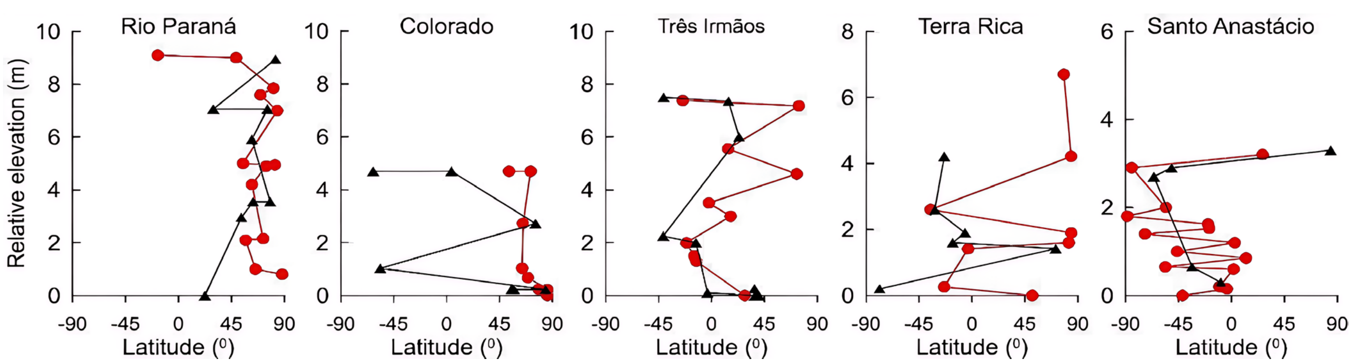

Figure 4 VGP latitude variation along the relative elevations for each investigated section. Red symbols indicate results from the thermal demagnetization, and the black symbols are from the AF demagnetization.

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4. Discussion

A paleomagnetic pole for the Caiuá Group was calculated based on all studied sections, giving unit weight by specimen or block mean whenever the case. However, the Paraná and the Colorado sections contributed about 62% of the 29 sites included in the calculation after applying the Vandamme (1994) site selection method, which offers an objective way to exclude those site results that represent anomalous or transitional directions and do not represent only the record of the paleosecular variation of the geomagnetic field. Only the Paraná (except the very top site of the section) and the Colorado sections presented a smoother paleomagnetic record of normal polarity. The other sections showed significant variations and

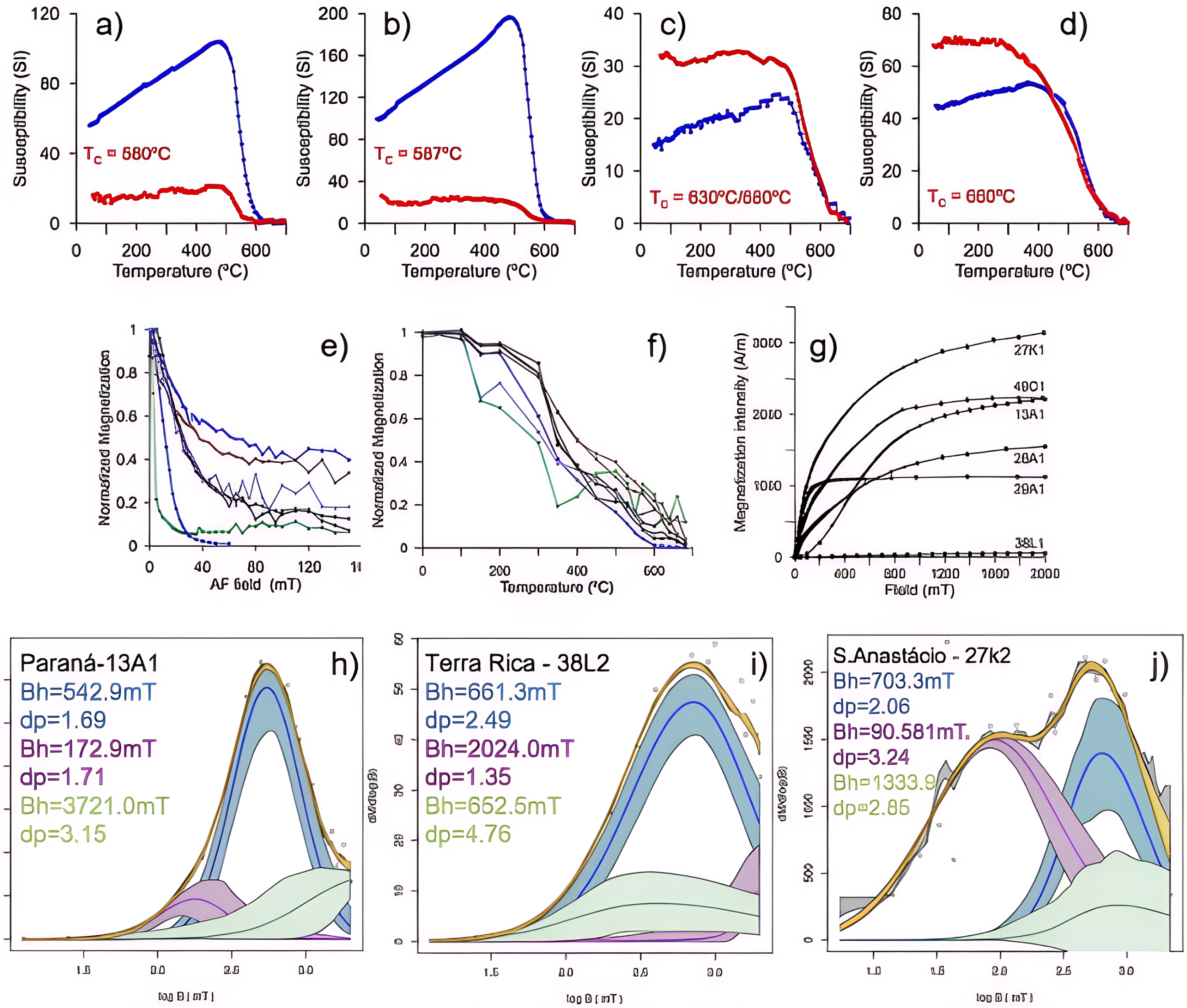

Figure 5 Thermomagnetic curves for representative samples from the Rio Paraná (a, b, c) and Santo Anastácio (d) formations. The red lines are the heating stage, and the blue lines are the cooling stage. Characteristic magnetization variation during AF (e) and thermal (f) cleaning. Isothermal magnetization acquisition curves (g) and the coercivity spectra (j to i) for some representative samples using the IRM unmixing protocol by Maxbauer *et al.* (2016). The blue, purple, and green lines present the three fitted components. The shaded areas correspond to the 95% confidence interval on each element. The mean remanence coercivity (Bh) dispersion is given by parameter (dp).

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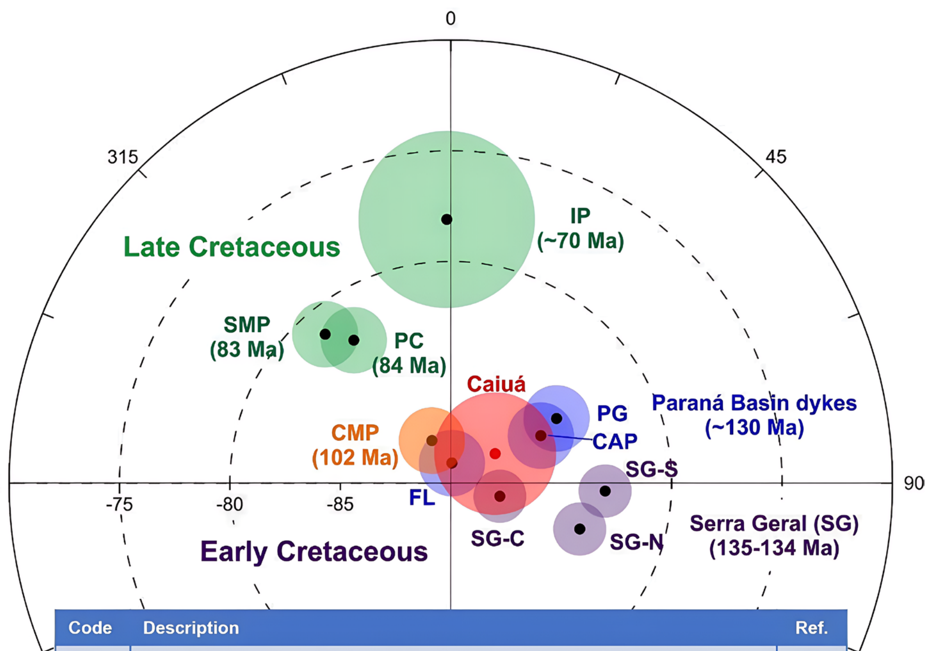
many anomalous (45° ≥ latitude ≥ -45°) VGPs that cannot be considered for the pole calculation. The Terra Rica and Morro Três Irmãos sections are very close and display similar patterns, recording normal to transitional fields. The Santo Anastácio section is highly variable, but data indicate transitional to reverse field (latitude ≤ -45°). In this case, the high dispersion may be due to spurious magnetization or unremoved secondary components. Still, considering that the Santo Anastácio Formation corresponds to the top of the sequence (Batezelli, 2010), it is reasonable to admit a migrating record from a stable (all normal polarity) to a changing field toward a reverse polarity chron.

The Caiuá paleomagnetic pole (Figure 6) is of mixed polarity and plots at 87.4 °S 56.6 °E (N = 29, A_{95} = 6.5, k = 18) close to the Early Cretaceous poles from the Paraná basalts and related dyke swarms and far from the Late Cretaceous which is well constrained by the high-quality paleomagnetic poles from the Serra do Mar alkaline dykes (Ernesto and Raposo, 2023) and the Poços de Caldas Complex (Montes-Lauar *et al.*, 1995). For comparison, Figure 6 includes the pole from the Cabo de Santo Agostinho magmatic rocks (Font *et al.*, 2009), named Cabo Magmatic Province (CMP), Ar/Ar dated at 102 Ma (Nascimento *et al.*, 2003). Therefore, the age for the Caiuá pole must not be younger than that age and must be placed within the Early Cretaceous. Considering the



Code	Description	Ref.
SG	Serra Geral Formation (S, N, C = southern, northern and central regions)	#1
PG	Ponta Grossa dykes	#2
CAP	Central Alkaline Province dykes, Paraguay	#3
FL	Florianópolis dykes	#4
CMP	Cabo Magmatic Province	#5
SMP	Serra do Mar Magmatic Province, alkaline dykes	#6
PC	Poços de Caldas Complex	#7
IP	Itatiaia and Passa Quatro complexes	#7

Figure 6 The Caiuá paleomagnetic pole compared with other poles from the Paraná Basin and the alkaline magmatism surrounding the basin. Color circles are proportional to the A95 cone of confidence and indicate poles of similar ages: green for the Late Cretaceous, blue, and purple for the Early Cretaceous. References are [1]Ernesto *et al.* (2021), [2]Ernesto *et al.* (1999), [3]Ernesto *et al.* (1996), [4]Raposo *et al.* (1998), [5]Font *et al.* (2009), [6]Ernesto and Raposo (2023), [7]Montes-Lauar *et al.* (1995).

mixed polarities in the Caiuá Group, the age must be older than 120 Ma as the Cretaceous Normal Superchron ranges between 120 and 83 Ma (Ogg, 2020).

The uncertainty of the Caiuá pole given by the A_{95} statistical parameter (Fisher, 1953) includes, at least partially, the poles from the dyke swarms in the Paraná Basin and even the basalts from the central area (between the Uruguay and Piquiri lineaments: Figure 1a), the most tectonized region in the Basin (Ernesto *et al.*, 2021; Jacques *et al.*, 2014). On the other hand, it differs from the two other Paraná basalt poles, especially the one for the northern region (north of the Rio Piquiri lineament), where the studied area is inserted.

In Figure 6, a mean age of about 130 Ma is indicated for the dyke swarms, although an age of about 134 Ma is attributed to both Ponta Grossa and Florianópolis dyke swarms (Almeida *et al.*, 2018; Florisbal *et al.*, 2014) and ~126 Ma for Central Alkaline Province in Paraguay (Gomes *et al.*, 2013). Assuming that the magnetization of the Caiuá Group has the same age as the main dyke swarms (~134 Ma), the lithospheric subsidence that allowed the accumulation of those sediments, was active during the extensional phase of the continental rifting following the model by McKenzie (1978). An upper age limit to the Caiuá sedimentation is defined by the beginning of the Normal Polarity Superchron at about 120 Ma (Barremian-Aptian limit; Ogg, 2020).

This result agrees with previous works like Fulfaro *et al.* (1999), Dias-Brito *et al.* (2001) and Batezelli (2010; 2017). The last author also considered the age of 120 Ma for the Caiuá Group, based on the basin analysis and the pterosaurs bone fragments content (Fragoso *et al.*, 2013; Guimarães *et al.*, 2012), which occurrence was dated at 120 Myr in Chinese tuffs (Wang and Zhou, 2003).

5. Concluding Remarks

Four sections of the Rio Paraná Formation and one of the Santo Anastácio Formation (paleosol) were sampled for the paleomagnetic work. The magnetic remanence showed significant variations throughout the paleosol section. Most sites gave anomalous directions, which may be associated with the chemical process of remanent acquisition or to a transitional field, as a reversed magnetization direction was detected in the section. However, other two sections of the Rio Paraná Formation (draas) showed similar behavior. Nick *et al.* (1991) showed early magnetization in paleosols in a lower Pennsylvanian carbonate sequence in Arizona. Therefore, the Santo Anastácio results are considered for the paleomagnetic pole calculation. Consequently, Caiuá paleomagnetic pole is of mixed polarity and plots at 87.4 ºS 56.6 ºE (N = 29, A_{95} = 6.5°, k = 18) close to the Early Cretaceous poles from the Paraná basalts and related dyke swarms and far from the Late Cretaceous which is well constrained by the high-quality paleomagnetic poles from the Serra do Mar alkaline dykes and the Poços de Caldas Complex. An upper age limit to the Caiuá sedimentation is defined by the beginning of the Normal Polarity Superchron at about 120 Ma (Barremian-Aptian limit), reinforcing previous stratigraphic works by Fulfaro *et al.* (1999), Dias-Brito *et al.* (2001) and Batezelli (2010; 2017).

Contributions of authors

(1) Conceptualization: ME, AB, ARS; (2) Analysis or data acquisition: ME, GCM, PGO; (3) Methodologic/technical development: ME, GCM; (4) Writing of the original manuscript: ME; (5) Writing of the corrected and edited manuscript: ME, AB, ARS; (6) Graphic design: ME; GCM; (7) Fieldwork: ME, AB, ARS; (8) Interpretation: ME, GCM; (9) Financing: ME.

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Conflict of interest

The authors declare that there are no interest conflicts of any kind

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