Archaeological and Anthropological Sciences (2025) 17:78
https://doi.org/10.1007/s12520-024-02158-3

RESEARCH

The Guaraní expansion through the Lowlands of South America

Daniel Loponte[1] · Mirian Carbonera[2] · Fernanda Schneider[1] · Andrés Gascue[3] · Rafael Guedes Milheira[4] · Marcos César Pereira Santos[5] · Juliano Bitencourt Campos[6] · Jedson Cerezer[7] · Antoine Lourdeau[8] · Alejandro Acosta[1] · Noelia Bortolotto[3] · Jairo Rogge[9] · Neli Teresinha Machado[10] · Sheila Ali[11] · Maricel Pérez[11] · Dione da Rocha Bandeira[12] · Isabella Muller[13] · Jaqueline Borger[14]

Received: 23 April 2024 / Accepted: 28 December 2024

Abstract
This study examines the expansion of Amazonian forager-horticulturalists grouped within the Guaraní archaeological unit, who migrated from southwestern Amazonia to southeastern South America, spanning much of the La Plata basin and the Atlantic coastal slope of southeastern Brazil, covering over 2500 km in a relatively short period. This process, marked by rapid expansion and extensive territorial coverage, represents one of the most remarkable migrations recorded among known pre-industrial societies. The initial expansion probably began in southwestern Amazonia, progressing southeastward to the headwaters of the La Plata basin, where this population appears as a weak archaeological signal around 500 CE. Approximately 800 years later, these Amazonian groups reached the Río de la Plata estuary, 1400 km farther south. Based on calibrated age ranges, the spatial distribution of Guaraní sites across the basin, and the application of various statistical methods (Silhouette Coefficient Analysis, Hierarchical Cluster Analysis, Principal Components Analysis, and Summed Probability Distribution of radiocarbon ages), this expansion was divided into four clusters or phases, reflecting a complex migratory process. In addition to redefining the dynamics of Guaraní expansion, this study provides a better alignment with linguistic dispersion models of these populations and offers new perspectives on how canoeing societies, in general, can rapidly spread across a vast territory within a brief archaeological timeframe.

Keywords Guaraní expansion · Demic diffusion · Human past migrations · Guaraní archaeology · South American lowlands · Forager-horticulturalists · Migration rates

Introduction

The Guaraní archaeological unit[1] refers to the material culture and related behaviors of ancient populations of forager-horticulturalists from the late Holocene who expanded from the southern Amazonia to the La Plata basin, reaching the Río de la Plata River, approximately 2500 km south of their Amazonian homeland. The bulk of this migratory process took place along the waterways of the La Plata basin and the Atlantic slope of southeastern Brazil, complemented by shorter overland movements. South American and European Ethnography and Archaeology have studied the Guaraní expansion since the end of the nineteenth century to the present day. The first radiocarbon ages began to be incorporated from the 1960s onwards (Long 1965), aiding in a better understanding of the chronology of this process. In recent decades, Guaraní archaeology has experienced a significant increase in research, mainly conducted in Brazil, Argentina, and Uruguay, resulting in published papers, unpublished thesis and reports of cultural resource management projects. This growing body of information enables us to conduct an updated analysis of the Guaraní expansion, utilizing various statistical tools to examine its spatio-temporal structure by

[1] The concept of archaeological unit we use here refers to groupings of formal properties of the archaeological record that reflect the lifestyle and material culture of past populations. These formal properties are synthesized under an archaeological name or label (e.g., Chavín, Clovis, Hopewell, Hohokam, etc.). These labels, while generally prioritizing the central tendency measures, allow for the rapid identification of associations among various attributes within the archaeological record. Additionally, they are useful for identifying past populations, constructing phylogenetic frameworks, analyzing cultural evolution, and communicating these details to others (see different positions in Gamble et al. 2005, Harmon et al. 2006, O'Brien and Lyman 2002, O'Brien et al. 2010, Riede 2011; Tehrani and Riede 2008).

Extended author information available on the last page of the article

addressing five key components. First, we will consider its antiquity—when the occupation of the La Plata River basin began. Second, the focus shifts to exploring where this colonization initially started. The third topic examines the spatial and temporal expansion, discussing when each major area was populated. The fourth objective focuses on expansion rates, and finally, we will assess whether it is possible to identify demographic pulses. Additionally, we will address secondary issues relevant to this study, such as the technical validity of some key ages and migration routes, methods and approaches for presenting chronological databases, settlement patterns, colonization strategies, site location, and the importance of further research to refine chronological data.

Although this work focuses on the Guaraní expansion process, which followed a southeastern dispersal axis from the southwestern Amazon, other populations of the Tupí linguistic family, such as the Tupinambá—whose archaeological record closely resembles that of the Guaraní—underwent a similar expansion process during a roughly contemporaneous period, though directed toward the northeast. Consequently, the main areas of convergence between the Guaraní and the Tupinambá were located in the states of Paraná and São Paulo. As a result, their territories show minimal overlap. Studies suggest that in frontier zones, such as the upper Paranapanema River, which separates the states of São Paulo and Paraná, exchanges of artifacts and knowledge likely occurred, as evidenced by ceramic styles (Brochado 1984; Noelli 2004; Kashimoto and Martins 2009; Corrêa 2009, 2014). Since the Tupinambá expansion and that of other Tupí-Guaraní linguistic groups occurred in different areas, these processes involve distinct datasets that require separate detailed analyses, which will not be addressed here (for more information on these other processes, see Brochado 1984; Noelli 2004; Martins et al. 1999; Kashimoto and Martins 2008; Corrêa 2009, 2014; Iriarte et al. 2017; Gregorio de Souza et al. 2020; Riris and Silva 2021).

The Guaraní archaeological unit

The Guaraní archaeological unit reflects the material culture and associated behaviors of ancient forager-horticulturalists from the late Holocene, belonging to the Tupí-Guaraní language family, specifically the Guaraní subgroup (O'Hagan et al. 2019). This connection is verifiable, as the territory where the Guaraní archaeological record is found closely corresponds to the distribution of populations who, at the time of first contact with European travelers, spoke what is now referred to as Southern Guaraní or Group III (Ferraz Gerardi et al. 2023). The Guaraní archaeological record is located in the same areas as the human groups to whom the Spanish applied the exonym "Guaraní," whose language is well documented in numerous early historical records. In addition, the most representative ceramic vessels found at Guaraní archaeological sites match in size and shape with those made by ethnographic or historical Guaraní populations (Ambrosetti 1895; Brochado et al. 1990; Brochado and Monticelli 1994; La Salvia and Brochado 1989). There are many other similarities of this kind, some subtle due to their symbolic or behavioral nature, while others are more obvious, such as labial ornaments or the style of smoking pipes found at archaeological sites, which reflect those documented among ethnographic Guaraní populations from the 16th to 18th centuries. Likewise, we could not connect the ethnographic panorama of southeastern South America with the extensive Guaraní archaeological record that spans into the historical period without acknowledging that the immediate pre-colonial ancestors of these populations produced it. Finally, there is no historical evidence, not even minimal, suggesting the existence of another pre-Columbian population that could account for the physical record known as the Guaraní archaeological unit, whose settlements fully extend into the historical period.

These Guaraní archaeological assemblages are well-identified thanks to consistent associations of various traits of their material culture, and several specific behaviors. Among the foremost is pottery, especially those pots exhibiting corrugated surfaces that possess a remarkable stylistic unity. The same applies to their polychromic ceramics, where, systematically, colors such as red, orange, brown and black were used to create highly characteristic geometric motifs that acquire an emblemic style (in the sense of Wiessner 1983), primarily applied over pre-firing white slips (Prous and Lima 2008). To a lesser extent, designs in white or black were also executed on red backgrounds, on the natural surface of uncolored paste, or on colorless slips. The vessel's typology includes very specific and recurring types in shape and size, which are certainly emblemic as well. Several authors have identified or suggested a correlation between the shapes and decoration of archaeological vessels and the respective emic and functional categories for the main Guaraní pottery types (Ambrosetti 1895; Brochado et al. 1990; Brochado and Monticceli 1994, among others). The Guaraní record also includes distinctive ornamental artifacts, among which are T-shaped labrets with long rounded spikes, mostly crafted in quartz and, in smaller quantities, in resin or bone. Pendant ornaments shaped like gourds or pears, triangular and quadrangular earrings made of bone and stone, and clay-smoking pipes with a highly characteristic style are frequent. In Guaraní assemblages, square and neckless axe heads, as well as whetstones likely used to shape and maintain their edges or other tasks such as straightening arrow shafts or polishing lip ornaments, are quite common (Figs. 1 and 2).

Guaraní mortuary practices included primary and secondary burials, some of them in funerary urns, which was a common practice among pre-Columbian Amazonian

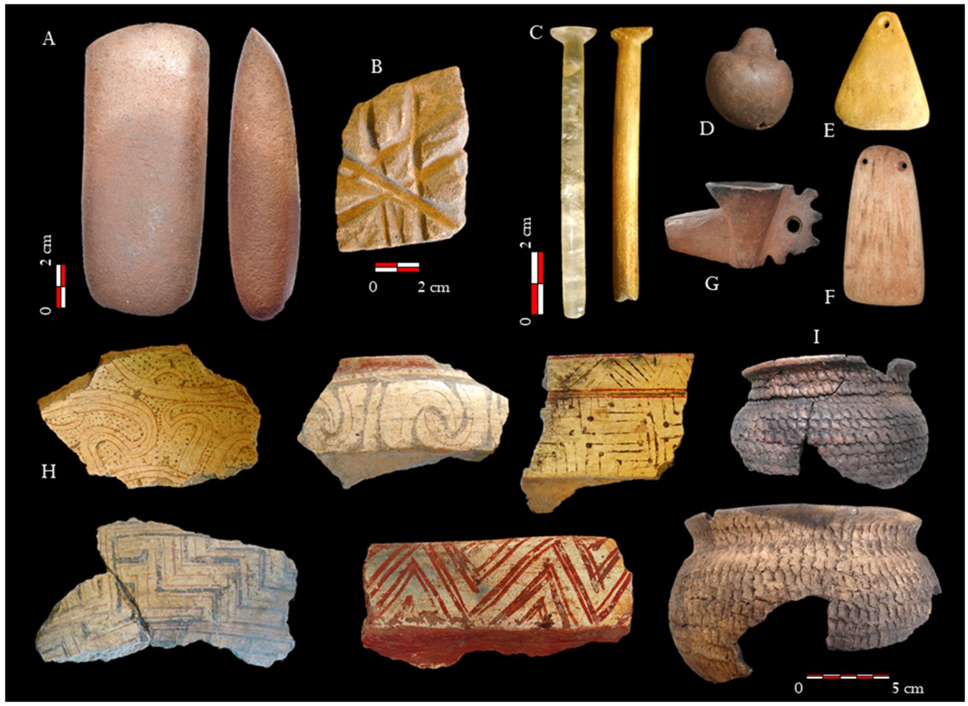

Fig. 1 Examples of the Guaraní record. **A**: Rectangular neckless stone axe head. **B**: Whetstone. **C**: Labrets (quartz and bone). **D**: Ceramic pendant. **E**–**F**: bone pendants. **G**: Ceramic smoking pipe. **H**: painted pottery with typical Guaraní geometrical style (red–black on white slip). **I**: Corrugated vessels. Scales are approximate

Fig. 2 Examples of Guaraní vessels

populations. Urn burials may contain one or more individuals (see different studies about Guaraní mortuary patterns in César 1966; Müller and de Souza 2011; Cristante 2018; Loponte et al. 2011; Loponte and Acosta 2013; Mazza et al. 2016; Carbonera et al. 2018; Carbonera et al. 2024). The burials might have funerary items (vessels, personal adornments, instruments) or lack them. In the latter case, it is difficult to know if there were perishable materials accompanying the body. Male burials also may include axes and labrets. Subsistence patterns also followed an Amazonian model, including gathering wild plants, slash-and-burn polyculture and garden hunting. The main crops were tropical tubers (sweet potatoes, yams, cassava), peanuts, beans, pumpkins, and especially maize, with a substantial enough intake to affect the isotopic values of their diets (Carbonera et al. 2022; Loponte et al. 2016; Loponte 2020). Along the Atlantic coast of Brazil, these interior-origin populations quickly adapted to new resources, incorporating marine foods (Admiraal et al. 2023; Rosa 2006). While Guaraní villages seemed to have had numerous pets from wild species, the only domesticated species known so far was *Cairina moschata* (Muscovy Duck), an Anatidae endemic to the tropics of South America, mentioned in historical chronicles (e.g., Schmidl 1948 [1536 – 1554]). However, its identification in the faunal record has been elusive so far (Acosta et al. 2019). Although the Guaraní population expanded into areas where other pre-Columbian populations had dogs (Loponte et al. 2023; Milheira et al. 2016), they do not seem to have adopted them until historical times.

Their settlements also follow a typical Amazonian pattern, selectively occupying tropical and subtropical lowland forests, generally avoiding drained or dry open field areas and environments 600 m above sea level, where rainforests do not thrive. Some few exceptions are observed in specific areas of the states of Mato Grosso do Sul and Rio Grande do Sul states and Corrientes province, exceptions that we will analyze elsewhere.

Guaraní villages were mostly situated immediately adjacent to watercourses. The use of canoes allowed them to cover extensive exploration ranges, facilitating the colonization of new spaces and fostering social, political, and economic cooperation with distant settlements. Guaraní villages could consist of hundreds of individuals, forming a complex socio-political organization across the territories (see further discussions in Noelli 1993; Soares 1997; Milheira 2014, among others).

European chroniclers of the sixteenth century described the existence of some Guaraní fortified settlements with palisades, ditches, and lines of stakes, located in areas where a bellicose scenario prevailed, such as at the confluence of the Paraguay and Pilcomayo rivers, where the Guaraní faced resistance from previously settled indigenous Chaco societies. During the colonial period, the Guaraní population experienced a massive loss of their lands in the tropical forests and was also forced to move from the coast to the interior. Between the sixteenth and eighteenth centuries, various indigenous societies, including different ethnic groups collectively labeled as "Guaraní," were resettled in Jesuit missions across Brazil, Argentina, and Paraguay. This resulted in profound changes to their traditions, language, religion, social structures, and political organization. Although demographic records are ambiguous, estimates suggest there were potentially up to one million Tupí-Guaraní individuals prior to European contact (Fausto 1992). Presently, according to the Brazilian Institute of Geography and Statistics, the number of Tupí-Guaraní speakers may not surpass 250,000 individuals.

The dispersal of the Tupi-Guaraní

Around 2500 BP (~ 500 CE), a division likely occurred between the Tupi-Guaraní and Awetí language families in the upper courses of the Xingú and Tapajós rivers in northeastern Amazonia (Ferraz Gherardi et al. 2023) or in the lower Xingú River basin (O'Hagan et al. 2019). Linguistic evidence suggests that the initial stage of the Tupi-Guaraní branch emerged approximately 1750 years ago (~ 250 CE) and that the Southern branch began to develop around 1250–1300 BP (Ferraz Gherardi et al. 2023, Fig. 6). At some point, the Southern branch, also known as Group III (Ferraz Gherardi et al. 2023), may have included populations whose cultural assemblages correspond to the Guaraní archaeological unit.

As discussed in Sect. "Results", these assemblages are detected in the upper Paraná basin around 500 ± 100 CE (~1500 ± 100 BP). However, archaeological studies have identified sites in Southwestern Amazonia dating back ~ 4000 years BP that feature ceramics with several stylistic and typological similarities to Guaraní pottery. Some of these resemblances are so striking that they have been designated as "Proto-Tupiguaraní" or directly "Tupiguaraní Tradition." Nevertheless, the current archaeological data remains insufficient and fragmented to fully address the complexity surrounding the origins of the Guaraní record. Moreover, the chronology of these assemblages requires further investigation (see various studies and perspectives in Almeida 2013; Caldarelli 2008; Miller 2009; Gregorio de Souza et al. 2020; Zimpel 2009, 2018, among others).

Beyond chronological and evolutionary considerations regarding the origin of Guaraní archaeological assemblages, the expansion of these Amazonian horticulturists extended from the southwestern Amazon to the Atlantic Forest, carrying numerous previously developed cultural traits such as corrugated vessels and polychrome geometric decoration (Brochado 1973, 1984). The newly colonized area did not represent a significant ecological change, as the Atlantic Forest is similar to the Amazon rainforest. Although these two forests are separated by a semi-arid diagonal and open wetlands (Cerrado and Pantanal, respectively), they have been more or less connected throughout their evolutionary history, depending on the spatial fluctuations of their borders. This proximity, along with climatic fluctuations, has facilitated the expansion of various organisms, including human populations such as the Guaraní (Batalha-Filho et al. 2013; Ledo and Colli 2017; Machado et al. 2021) (Fig. 3).

Several studies have explored the relationship between the expansion of the Tupi-Guaraní language family and climatic fluctuations (e.g., Iriarte et al. 2017 and the sources cited therein). While these efforts have significantly contributed to our understanding of the factors, among others, that may have driven Guaraní expansion, substantial gaps in both archaeological and paleoclimatic data persist, making it difficult to establish a detailed and cohesive connection between these two types of evidence to date.

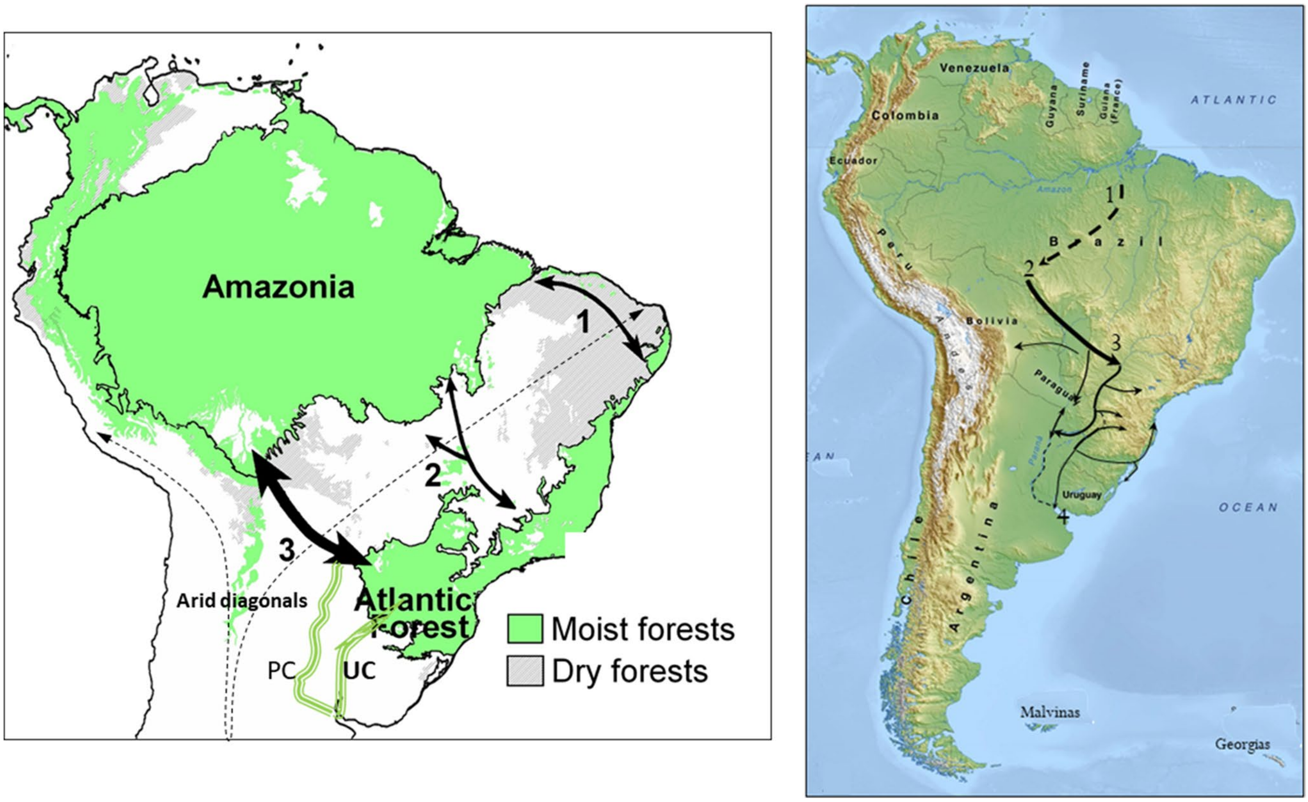

Fig. 3 Left: main biological corridors between Amazonia and the Atlantic Forest 1 = Northeastern route. 2 = Central route. 3 = Southwestern route. PC = Southern Paraná Corridor. UC = Uruguay corridor (taken and modified from Machado et al. 2021, and www.conexoesamazonicas.org). Right: General outline of the southern territorial spread of the Tupi-Guaraní language family from the lower Xingú (1) to southwestern Amazonia (2), headwaters of the La Plata Basin (3) and Río de la Plata River (4) (see also Ferraz Gerardi et al. 2023, Fig. 4)

Materials and methods

Radiocarbon and TL ages

For this study, we considered several works that compiled radiocarbon and TL ages from Guaraní sites (Acosta et al. 2019; Brochado 1971, 1984; Bonomo et al. 2015; Cerezer 2017; Corrêa 2009; Kashimoto and Martins 2008, 2009; Loponte et al. 2011, 2024a, b, 2025; Martins et al. 1999; Milheira 2010, 2014; Noelli 1999–2000; Rogge 2005; Schmitz n.d.; Schneider 2014, 2019, among others; see Table 1). This database was refined and expanded with several new radiocarbon analyses, resulting in a total of 228 radiocarbon ages and 85 thermoluminescence (TL) ages (n = 313), which are listed in Table 1. Approximately 70% of the TL ages were obtained by Martins et al. (1999) and Kashimoto and Martins (2008, 2009), where *in-situ* radiometric doses were measured (Hatsue Tatumi pers. comm., 2024). Most of these TL-dated fragments were recovered from archaeological layers, although some originated from surface contexts. In all cases, the external surfaces of the fragments were scraped to ensure proper sampling and accurate TL dating, following standard protocols (e.g., Aitken 1985, 1998; Kusiak et al. 2011).

All radiocarbon ages in this study were calibrated using the SHCal-20 curve with the OxCal program (Bronk Ramsey 2021; Hogg et al. 2020). The chronological ranges of TL ages were expressed based on the errors reported by each laboratory, referencing either the publication date or the analysis date when available. Regardless, the potential resulting errors are limited to a few years, or at most one or two decades, which does not impact the analyses presented here. Throughout the text, radiocarbon years before present (^{14}C years BP) and their calibrated ranges in BCE/CE format (Before Common Era/Common Era) are used.

Location of the sites

The location of the archaeological sites was determined based on information available in the literature. In some cases, these locations are approximate, leading to minor distortions of a few kilometers that do not affect the analysis in this study. We also benefited from the site locations compiled by Bonomo et al. (2015), but we introduced several

Table 1 Guaraní chronological database. *See Supplementary Text

#	Cluster	SITE	CODE	COUNTRY	STATE	LAT	LONG	DATE	±1σ	M	AGE CE		Midpoint	LAB	REFERENCES
1	C1	Ragil		BRAZIL	SP	-22.7380	-51.0290	1668	170	TL	160	500	330	FATEC ND	Faccio (1998); Noelli (1999–2000)
2	C1	João Batista		BRAZIL	PR	-24.2140	-51.5060	1519	200	TL	288	688	488	-	Corrêa (2009)
3	C1	Lagoa Seca	PR-FI-118	BRAZIL	PR	-25.4630	-54.6090	1625	60	14C	343	633	488	SI-5021	Chmyz (1983) in Noelli (1999–2000)
4	C1	Boreví 1	PR-FI-99	BRAZIL	PR	-25.3960	-54.4560	1565	70	14C	389	650	520	SI-5019	Chmyz (1983) in Noelli (1999–2000)
5	C1	Restaurante Ivaí 2	PR-FL-21	BRAZIL	PR	-23.5010	-52.3330	1490	45	14C	530	670	600	SI-1011	Stuckenrath and Mielke (1973)
6	C2	Albino Mazzari	RS-MJ-60	BRAZIL	RS	-29.4800	-53.6000	1475	80	14C	427	773	600	SI-2203	Brochado (1971, 1984)
7	C1	Ribeirão Taquari 1	MS-PR-45	BRAZIL	MS	-21.4170	-52.0188	1380	40	14C	643	774	709	Gif 12026	Kashimoto and Martins (2009)
8	C1	Fazenda Dona Carlota 4	PR-FI-142	BRAZIL	PR	-25.5450	-54.5740	1395	60	14C	582	850	716	SI-5033	Chmyz (1983) in Noelli (1999–2000)
9	C2	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	1200	150	TL	649	949	799	FATEC-148	Kashimoto and Martins (2008)
10	C1	José Vieira*		BRAZIL	PR	-23.3630	-52.9080	1287	200	14C	411	1210	811	81 (or Gsy 81)	Laming and Emperaire (1959), Laming Emperair (1968)
11	C2	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	1170	140	TL	689	969	829	FATEC-164	Kashimoto and Martins (2008)
12	C2	Antônio D. Castro		BRAZIL	SC	-27.5181	-51.8777	1240	15	14C	773	888	831	UCIAMS 252935	Loponte et al. (2024a)
13	C2	Capané 3	RS-MJ-101	BRAZIL	RS	-29.8360	-53.1700	1255	100	14C	650	1019	835	SI-2201	Schmitz and Brochado (1972)
14	C2	Taquapelagai	PR-FI-101	BRAZIL	PR	-25.5010	-54.0300	1235	60	14C	685	989	837	SI-5016	Chmyz (1983) in Noelli (1999–2000)
15	C2	SP-BA-7	SP-BA-7	BRAZIL	SP	-23.5830	-49.6000	1195	80	14C	682	1026	854	SI-1009	Chmyz (1967). Stuckenrath & Mielke (1973)
16	C2	Rio Paranapanema		BRAZIL	SP	-24.0970	-49.4100	1190	50	14C	772	994	883	-	Chmyz (1977) in Corrêa (2009)

Table 1 (continued)

#	Cluster	SITE	CODE	COUNTRY	STATE	LAT	LONG	DATE	±1σ	M	AGE CE		Midpoint	LAB	REFERENCES
17	C2	Linha Uruguay Sul 1	RS-VZ-4	BRAZIL	RS	-27.8375	-55.0210	1220	120	14C	643	1140	892	SI-708	Stuckenrath and Mielke (1973)
18	C2	Ragil II		BRAZIL	SP	-22.7550	-51.0110	1093	100	TL	805	1005	905	FATEC ND	Faccio (1998)
19	C2	Albino Mazzari	RS-MJ-60	BRAZIL	RS	-29.4800	-53.6000	1180	70	14C	693	1135	914	SI-2204	Schmitz and Brochado (1972); Schmitz Ms.
20	C2	Aldeia da ZPE (M19)		BRAZIL	SC	-28.2166	-48.6967	1050	150	TL	799	1099	949	-	Lavina (1999)
21	C2	Aldeia da ZPE (Urna 1)		BRAZIL	SC	-28.2166	-48.6967	1040	110	TL	849	1069	959	-	Lavina (1999)
22	C2	Porto Casanova 2	SP-AS-14	BRAZIL	SP	-22.7670	-51.0500	1130	150	14C	662	1220	941	SI-422	Stuckenrath and Mielke (1970)
23	C2	Aldeia da ZPE (U7)		BRAZIL	SC	-28.2166	-48.6967	1000	110	TL	889	1109	999	-	Lavina (1999)
24	C2	SC-U-69		BRAZIL	SC	-27.1406	-53.4215	1070	100	14C	773	1217	995	SI-549	Stuckenrath and Mielke (1972); Schmitz, Ms.
25	C2	Geraldo	PR-ST-1	BRAZIL	PR	-23.5000	-52.5000	1065	95	14C	774	1218	996	SI-695	Stuckenrath and Mielke (1973)
26	C2	Bassani	RS-M-35	BRAZIL	RS	-29.7670	-50.0830	1070	110	14C	771	1226	999	SI-413	Stuckenrath and Mielke (1970)
27	C2	Santa Rita do Pardo 2	MS-PD-07-SR2	BRAZIL	MS	-21.7070	-52.6213	980	100	TL	919	1119	1019	FATEC-402	Kashimoto and Martins (2008)
28	C2	Alvim		BRAZIL	SP	-22.3190	-51.4990	978	100	TL	914	1114	1014	-	Faccio (1992)
29	C2	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	950	115	TL	934	1164	1049	FATEC-163	Kashimoto and Martins (2008)
30	C2	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	930	110	TL	959	1179	1069	FATEC-166	Kashimoto and Martins (2008)
31	C2	Alvim		BRAZIL	SP	-22.3190	-51.4990	906	90	TL	996	1176	1086	-	Faccio (1992)
32	C2	Córrego Lalima	MS-MI-01	BRAZIL	MS	-20.5678	-56.2823	970	60	14C	995	1221	1108	Beta-238765	Bespalez (2010)
33	C2	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	835	90	TL	1074	1254	1164	FATEC-162	Kashimoto and Martins (2008)
34	C2	Panambí 3		ARGENTINA	MIS	-27.7287	-54.9116	920	70	14C	1029	1270	1150	LP-176	Sempé and Caggiano (1995)

Table 1 (continued)

#	Cluster	SITE	CODE	COUNTRY	STATE	LAT	LONG	DATE	±1σ	M	AGE CE		Midpoint	LAB	REFERENCES
35	C2	SC-PRV-02		BRAZIL	SC	-27.5233	-48.4236	920	50	14C	1034	1266	1150	CAMS 48545	De Masi (2001)
36	C2	Maracajú 1	MS-MJ-1	BRAZIL	MS	-21.7740	-55.3890	830	80	TL	1089	1249	1169	1TL/USP	Kashimoto and Martins (2009)
37	C2	Baixo Rio D´Duna		BRAZIL	SC	-28.1891	-48.7078	910	30	14C	1048	1266	1157	BETA-396226	Novasco et al. (2021)
38	C2	SP-BA-7	SP-BA-7	BRAZIL	SP	-23.5830	-49.6000	850	150	14C	900	1423	1162	SI-417	Stuckenrath and Mielke (1970)
39	C2	Fazenda Soares	RS-RG-002	BRAZIL	RS	-31.8470	-52.2220	890	40	14C	1050	1275	1163	SI-1190	Schmitz Ms.
40	C2	Aldeia do ZPE (M5)		BRAZIL	SC	-28.2166	-48.6967	810	85	TL	1104	1274	1189	ND	Lavina (1999)
41	C2	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	800	100	TL	1099	1299	1199	FATEC-139	Martins et al. (1999)
42	C2	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	795	95	TL	1109	1280	1195	FATEC-150	Martins et al. (1999)
43	C2	Porto Casa-nova 2	SP-AS-14	BRAZIL	SP	-22.8330	-51.1670	908	100	14C	991	1380	1186	SI-709	Stuckenrath and Mielke (1973)
44	C2	Lincoln Steu-ernagel	RS-MJ-53	BRAZIL	RS	-29.4170	-53.3320	900	95	14C	993	1378	1186	SI-1196	Schmitz Ms.
45	C2	Bassani	RS-M-35	BRAZIL	RS	-29.7670	-50.0830	870	100	14C	1020	1386	1203	SI-412	Schmitz Ms.
46	C2	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	795	10	TL	1194	1214	1204	FATEC-156	Martins et al. (1999)
47	C2	Isla de Arriba		URUGUAY	PU	-30.9926	-57.8786	860	85	14C	1028	1381	1205	-	Bracco et al. (2000) and comm. pers.
50	C2	SC-U-22		BRAZIL	SC	-27.1816	-53.6165	880	15	14C	1161	1266	1214	UCIAMS 267423	Loponte et al. (2024a)
48	C2	Mondaí 1	SC-U-53	BRAZIL	SC	-27.1736	-53.4989	770	100	14C	1048	1420	1234	SI-439	Mielke and Long (1969)
49	C2	Bom Jardin Velho	RS-G-14	BRAZIL	RS	-29.6289	-51.3729	745	115	14C	1047	1444	1246	SI-1198	Schmitz Ms.
51	C2	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	750	80	TL	1169	1329	1249	FATEC-89	Martins et al. (1999)
52	C2	Santa Rita do Pardo 2	MS-PD-07-SR2	BRAZIL	MS	-21.7070	-52.6210	750	75	TL	1174	1324	1249	FATEC-400	Kashimoto and Martins (2008)
53	C3	Cemitério Lagoa dos Esteves (M-1)		BRAZIL	SC	-28.8412	-49.2956	720	70	TL	1217	1357	1287	FATEC ND	Lavina (2000)
54	C3	Aldeia da ZPE		BRAZIL	SC	-28.2166	-48.6967	715	75	TL	1220	1370	1295	FATEC ND	Lavina (1999)

Table 1 (continued)

#	Cluster	SITE	CODE	COUNTRY	STATE	LAT	LONG	DATE	±1σ	M	AGE CE		Midpoint	LAB	REFERENCES
55	C3	484 A,2		ARGENTINA	COR	-27.5200	-56.7300	810	60	14C	1156	1386	1271	BETA 197128	Rodríguez (2009)
56	C3	Pedra Grande	RS-SM-7	BRAZIL	RS	-29.5500	-54.2500	800	40	14C	1188	1380	1284	SI-1003	Schmitz Ms.
57	C3	Jerônimo Rodrigues	RS-MJ-98	BRAZIL	RS	-29.7610	-53.2490	775	65	14C	1182	1394	1288	SI-2198	Schmitz Ms.
58	C3	Fazenda Dona Carlota 2	PR-FI-140	BRAZIL	PR	-25.5200	-54.4720	745	75	14C	1186	1405	1296	SI-5027	Chmyz (1983), Noelli (1999–2000)
59	C3	Sete Quedas 3	PR-PO-4	BRAZIL	PR	-24.0770	-54.247	760	40	14C	1225	1386	1306	SI-5039	Chmyz (1983), Noelli (1999–2000)
60	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	680	80	TL	1239	1399	1319	FATEC-149	Martins et al. (1999)
61	C3	Corredeira dos Caiuá	PR-JA-1	BRAZIL	PR	-22.9170	-50.0000	760	50	14C	1218	1391	1305	SI-140	Long (1965)
62	C3	ALP-AA-06		BRAZIL	SC	-27.1393	-53.0511	750	50	14C	1223	1392	1308	Beta-236425	Caldarelli (2010)
63	C3	Arroyo Fredes		ARGENTINA	BA	-34.1863	-58.5527	690	70	14C	1229	1423	1326	UGA-10789	Loponte and Acosta (2003)
64	C3	511 B		ARGENTINA	COR	-27.6370	-56.6150	684	170	14C	1026	1628	1327	Ingeis-1338	Rodríguez (1997, 2009)
65	C3	Rio dois Irmãos	PR-FI-112	BRAZIL	PR	-25.3970	-54.5780	700	55	14C	1270	1407	1339	SI-5036	Chmyz (1983), Noelli (1999–2000)
66	C3	Arnildo Drew	RS-MJ-87	BRAZIL	RS	-29.6780	-53.6440	695	55	14C	1272	1408	1340	SI-2200	Schmitz Ms.
67	C3	RS-VZ-52	RS-VZ-52	BRAZIL	RS	-27.4726	-53.9321	675	50	14C	1284	1405	1345	ND	Miller (2009)
68	C3	Alto Paraná 8	MS-PR-35	BRAZIL	MS	-21.6310	-52.0580	625	40	TL	1334	1414	1374	FATEC-189	Kashimoto and Martins (2008)
69	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	625	50	TL	1324	1424	1374	FATEC-146	Kashimoto and Martins (2008)
70	C3	Emílio Gramms		BRAZIL	SC	-27.1628	-53.0885	640	15	14C	1318	1402	1360	UCIAMS 252937	Loponte et al. (2024a)
71	C3	SC-CH-182		BRAZIL	SC	-27.2383	-52.7514	625	15	14C	1321	1406	1364	UCIAMS 267422	Loponte et al. (2024a)
72	C3	Boreví 2	PR-FI-104	BRAZIL	PR	-25.2690	-54.4780	625	55	14C	1295	1434	1365	SI-5020	Chmyz (1983), Noelli (1999–2000)
73	C3	SC-U-55*		BRAZIL	SC	-27.1068	-53.08219	620	80	14C	1277	1455	1366	SI-550	Stuckenrath and Mielke (1972)
74	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	610	75	TL	1314	1464	1389	FATEC-152	Kashimoto and Martins (2008)

Table 1 (continued)

#	Cluster	SITE	CODE	COUNTRY	STATE	LAT	LONG	DATE	±1σ	M	AGE CE		Midpoint	LAB	REFERENCES
75	C3	Quinteroi 5	MS-PR-08	BRAZIL	MS	-22.1593	-52.6606	610	60	TL	1329	1449	1389	FATEC-118	Kashimoto and Martins (2009)
76	C3	Maracajú 1	MS-MJ-1	BRAZIL	MS	-21.7743	-55.3896	610	50	14C	1299	1441	1370	Gif-8330	Kashimoto and Martins (2008)
77	C3	Santa Rita do Pardo 2	MS-PD-07-SR2	BRAZIL	MS	-21.7070	-52.6210	610	60	TL	1329	1449	1389	FATEC-399	Kashimoto and Martins (2008)
78	C3	Lagoa Mãe Luzia (M-2)		BRAZIL	SC	-28.8659	-49.3231	610	60	TL	1337	1457	1397	FATEC ND	Lavina (2000)
79	C3	Ilha Francisco Manuel	RS-C-71	BRAZIL	RS	-30.2653	-51.1632	610	50	14C	1299	1441	1370	ND	Gaulier (2001)
80	C3	485 A		ARGENTINA	COR	-27.5140	-56.7380	610	70	14C	1290	1450	1370	Beta-105247	Rodríguez (2009)
81	C3	Paineira	PR-FI-100	BRAZIL	PR	-25.2080	-54.4420	600	60	14C	1297	1449	1373	SI-5029	Chmyz (1983), Noelli (1999–2000)
82	C3	Rio Condor 5	PR-FL-15	BRAZIL	PR	-23.5000	-52.5000	590	70	14C	1291	1457	1374	SI-699	Brochado (1973), Stuckenrath and Mielke (1973)
83	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	605	70	TL	1324	1464	1394	FATEC-158	Kashimoto and Martins (2008)
84	C3	Pedra Grande	RS-SM-7	BRAZIL	RS	-29.5500	-54.2500	605	40	14C	1310	1440	1375	SI-1002	Stuckenrath and Mielke (1973)
85	C3	Cafezal 2	PR-FI-127	BRAZIL	PR	-25.2380	-54.3690	590	55	14C	1301	1451	1376	SI-5024	Chmyz 1983 in Noelli 1999–2000
86	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	550	70	TL	1379	1379	1379	FATEC-138	Kashimoto and Martins (2008)
87	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	600	80	TL	1319	1479	1399	FATEC-142	Martins et al. (1999)
88	C3	Río Ivinhema 1	MS-IV-09	BRAZIL	MS	-23.2440	-53.7150	600	57	TL	1342	1456	1399	FATEC-997	Kashimoto and Martins (2008)
89	C3	Fazenda Soares	RS-002-2	BRAZIL	RS	-31.8470	-52.2220	580	50	14C	1312	1454	1383	Beta-64560	Hilbert et al. (1997) in Carle (2002)
90	C3	Llamarada 1		ARGENTINA	COR	-28.3190	-58.0820	580	50	14C	1312	1454	1383	Beta-41941	Mujica (1995b, c)
91	C3	511 A		ARGENTINA	COR	-27.6370	-56.6150	570	50	14C	1316	1456	1386	Beta-197129	Rodríguez (2009)

Table 1 (continued)

#	Cluster	SITE	CODE	COUNTRY	STATE	LAT	LONG	DATE	±1σ	M	AGE CE		Midpoint	LAB	REFERENCES
92	C3	Olho D'água 1		BRAZIL	SC	-28.7917	-49.1972	560	40	14C	1324	1452	1388	Beta-280652	Milheira and De Blasis (2011)
93	C3	RS-T-114	RS-T-114	BRAZIL	RS	-29.2806	-52.1194	560	40	14C	1324	1452	1388	Beta-249391	Fiegenbaum (2009)
94	C3	Arroio Corrente 5		BRAZIL	SC	-28.6852	-49.0359	530	40	14C	1329	1461	1395	Beta-280654	Milheira (2010)
95	C3	PS-03-Totó		BRAZIL	RS	-31.7201	-52.1918	530	40	14C	1329	1461	1395	Beta-237665	Milheira (2008)
96	C3	Sibelco		BRAZIL	SC	-69.5611	-68.3233	550	60	14C	1307	1496	1402	Beta-262752	Milheira (2010)
97	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	595	70	TL	1334	1474	1404	FATEC-145	Kashimoto and Martins (2008)
98	C3	Ensenada del Bellaco		ARGENTINA	ER	-33.0915	-58.4349	526	45	14C	1325	1485	1405	AA-103895	Bonomo et al. (2015)
99	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	590	70	TL	1339	1479	1409	FATEC-161	Kashimoto and Martins (2008)
100	C3	Alto Paraná 12	MS-PR-39	BRAZIL	MS	-21.5110	-51.9930	580	40	TL	1379	1459	1419	FATEC-190	Kashimoto and Martins (2008)
101	C3	Lagoa da Velhinha		BRAZIL	SC	-28.8655	-49.3077	560	30	14C	1393	1449	1421	Beta-696116	Campos and Perin (2023)
102	C3	Rio Ivinhema 1	MS-IV-09	BRAZIL	MS	-23.2440	-53.7150	570	40	TL	1389	1469	1429	FATEC-996	Kashimoto and Martins (2008)
103	C3	Arroyo Negro (IU)		URUGUAY	RN	-32.4880	-58.1888	590	50	TL	1365	1465	1415	UCTL-1673	Farías (2005)
104	C3	RS-T-114	RS-T-114	BRAZIL	RS	-29.2885	-52.1195	592	67	TL	1349	1483	1416	LACIFID-USP	Kreutz (2008)
105	C3	Sítio Geraldo	PR-ST-1	BRAZIL	PR	-23.5000	-52.5000	610	120	14C	1215	1627	1421	SI-696	Stuckenrath and Mielke (1973)
106	C3	Segunda Corredeira	PR-FL-23	BRAZIL	PR	-23.5000	-52.3330	560	30	14C	1393	1449	1421	SI-700	Stuckenrath and Mielke (1973)
107	C3	Favaretto		BRAZIL	RS	-29.0451	-51.6259	540	30	14C	1401	1451	1426	Beta-205841	Machado (2008)
108	C3	Arnoldo Appelt	SC-VP-38	BRAZIL	SC	-27.2708	-52.3416	590	100	14C	1231	1623	1427	SI-826	Stuckenrath and Mielke (1973)
109	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	550	50	TL	1399	1499	1449	FATEC-90	Kashimoto and Martins (2008)
110	C3	Llamarada 1		ARGENTINA	COR	-28.3190	-58.0820	480	50	14C	1401	1460	1431	Beta-41944	Mujica (1995b, c)

Table 1 (continued)

#	Cluster	SITE	CODE	COUNTRY	STATE	LAT	LONG	DATE	±1σ	M	AGE CE		Midpoint	LAB	REFERENCES
111	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	545	65	TL	1389	1519	1454	FATEC-154	Kashimoto and Martins (2008)
112	C3	Uruguai 1	RS-URG-01	BRAZIL	RS	-27.1237	-53.0445	510	20	14C	1418	1455	1437	GifA-17403/ ECHo 2017	Carbonera et al. (2024)
113	C3	SC-CH-158	SC-CH-158	BRAZIL	SC	-27.2531	-52.7041	510	20	14C	1418	1455	1437	Beta-308754	De Masi (2012)
114	C3	SC-CH-197	SC-CH-197	BRAZIL	SC	-27.2773	-52.7030	510	20	14C	1418	1455	1437	Beta-308747	De Masi (2012)
115	C3	RS-LC-82	RS-LC-82	BRAZIL	RS	-30.3852	-50.3322	563	45	TL	1398	1488	1443	LVD-665	Rogge (2005)
116	C3	Baia da Onça 1	ON1	BRAZIL	MS	-22.3980	-52.9250	540	60	TL	1399	1519	1459	FATEC-117	Kashimoto and Martins (2008)
117	C3	Rio Amambai 1	AB-1	BRAZIL	MS	-23.9640	-55.1640	540	40	TL	1419	1499	1459	FATEC-127	Kashimoto and Martins (2008)
118	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	520	60	TL	1419	1539	1479	FATEC-159	Kashimoto and Martins (2008)
119	C3	Batista Rector	U-381	BRAZIL	SC	-27.4839	-51.8994	505	15	14C	1425	1455	1440	UCIAMS 252936	Loponte et al. (2024a)
120	C3	RS-NO-182	RS-NO-182	BRAZIL	SC	-27.2085	-52.7813	495	20	14C	1425	1459	1442	Beta -308750	De Masi (2012)
121	C3	Corpus		ARGENTINA	MIS	-27.1100	-55.5017	495	20	14C	1425	1459	1442	UCIAMS 134675	Carbonera and Loponte (2018)
122	C3	RS-NO-182	RS-NO-182	BRAZIL	SC	-27.2085	-52.7813	490	20	14C	1424	1460	1442	Beta-308751	De Masi (2012)
123	C3	Morro Bonito 2		BRAZIL	SC	-28.6089	-48.9839	510	40	14C	1398	1489	1444	Beta-262754	Milheira (2010)
124	C3	PS-03-Totó		BRAZIL	RS	-31.7114	-52.1734	510	40	14C	1398	1489	1444	Beta-282128	Alves (2012), Milheira (2014)
125	C3	Lagoa da Porteira 1	RS-LC-80	BRAZIL	RS	-30.4310	-50.6050	563	45	TL	1401	1491	1446	LVD-655	Schmitz and Sandrin (2009)
126	C3	RS-T-114	RS-T-114	BRAZIL	RS	-29.2806	-52.1194	490	30	14C	1411	1489	1450	Beta-388515	Schneider et al. (2017)
127	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	525	30	TL	1444	1504	1474	FATEC-165	Kashimoto and Martins (2008)
128	C3	Tapera	SC-LF-2/ FLN-58	BRAZIL	SC	-27.5940	-48.5010	550	70	14C	1297	1615	1456	SI-244	Rohr (1969), Long and Mielke (1967)
129	C3	Alto Paraná 13	MS-PR-40	BRAZIL	MS	-21.5041	-52.0738	460	50	TL	1489	1589	1458	FATEC-99	Kashimoto and Martins (2008)

Table 1 (continued)

#	Cluster	SITE	CODE	COUNTRY	STATE	LAT	LONG	DATE	±1σ	M	AGE CE		Midpoint	LAB	REFERENCES
130	C3	Passo Fundo	RS-M-16	BRAZIL	RS	-29.9330	-50.2170	540	100	14C	1289	1628	1459	SI-411	Miller (1967), Stuckenrath and Mielke (1970)
131	C3	Joaquim Bosquero	U-71 (T1)	BRAZIL	SC	-27.5330	-51.7676	530	70	14C	1301	1623	1462	Beta-118375	Beta Report (1998)
132	C3	SC-CH-119	SC-CH-119	BRAZIL	SC	-27.2384	-52.7611	470	20	14C	1433	1491	1462	Beta-308746	De Masi (2012)
133	C3	Rio Ferraria 1	PR-CT-54	BRAZIL	PR	-25.4760	-49.5300	528	70	14C	1303	1623	1463	Beta-22645	Chmyz (1983) in Noelli (1999–2000)
134	C3	Santa Rita	RS-SR-342	BRAZIL	RS	-29.9810	-51.5330	540	60	14C	1315	1615	1465	Beta-129548	Hilbert (1999)
135	C3	Porto de Areia 2	PR-QN-2	BRAZIL	PR	-23.5010	-52.5000	540	60	14C	1315	1615	1465	SI-697	Chmyz (1969a), Stuckenrath and Mielke (1973)
136	C3	Arnaldo M. Silva	RS-MJ-47	BRAZIL	RS	-29.8500	-53.3800	530	120	14C	1276	1655	1466	SI-816	Stuckenrath and Mielke (1973)
137	C3	Pesqueiro Barragem de Rosana	PR-NL-7	BRAZIL	PR	-22.6410	-52.8560	530	55	14C	1321	1612	1467	SI-6400	Chmyz and Chmyz (1986)
138	C3	Rancho Leôn-cio 2	PR-FL-5	BRAZIL	PR	-23.5000	-52.5000	470	100	14C	1312	1623	1468	SI-694	Chmyz (1969a), Stuckenrath & Mielke (1973)
139	C3	Llamarada 1		ARGENTINA	COR	-28.3190	-58.0820	520	50	14C	1326	1612	1469	Beta-41942	Mujica (1995b, c)
140	C3	Morro Bonito 1		BRAZIL	SC	-28.6063	-48.9639	520	50	14C	1326	1612	1469	Beta-262753	Milheira (2010)
141	C3	Fazenda Soares	RS-002-2	BRAZIL	RS	-31.8470	-52.2220	510	60	14C	1321	1623	1472	Beta-64284	Hilbert et al. (1997) in Carle (2002)
142	C3	Caxambu do Sul 1	SC-U-55	BRAZIL	SC	-27.1068	-53.0821	510	70	14C	1318	1627	1473	SI-547	Piazza (1969), Stuckenrath and Mielke (1972)
143	C3	Llamarada 1		ARGENTINA	COR	-28.3190	-58.0820	510	50	14C	1329	1616	1473	Beta-41945	Mujica (1995b, c)
144	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	505	60	14C	1323	1623	1473	FATEC-153	Kashimoto and Martins (2008)
145	C3	Llamarada 1		ARGENTINA	COR	-28.3190	-58.0820	500	60	14C	1324	1624	1474	Beta-41940	Mujica (1995b, c)

Table 1 (continued)

#	Cluster	SITE	CODE	COUNTRY	STATE	LAT	LONG	DATE	±1σ	M	AGE CE		Midpoint	LAB	REFERENCES
146	C3	Barra do Santo Cristo 1	----	BRAZIL	RS	-27.5680	-54.7200	500	70	14C	1322	1628	1475	LP-1874	Costa Angrizani (2012)
147	C3	São Carlos	SC-VX-5*	BRAZIL	SC	-27.0994	-53.0141	490	70	14C	1327	1628	1478	SI-548	Stuckenrath and Mielke (1972)
148	C3	Sete Quedas 2	PR-FO-3	BRAZIL	PR	-26.0840	-51.0340	490	60	14C	1329	1627	1478	SI-5040	Chmyz 1983 in Noelli (1999–2000)
149	C3	Puerto Esperanza		ARGENTINA	MIS	-25.9830	-54.643682°	428	26	14C	1446	1540	1493	AA-108382	This paper
150	C3	PSGPA-04-Ribes		BRAZIL	RS	-36.6576	-65.1385	510	70	TL	1428	1568	1498	LVD-1968	Milheira (2008, 2014)
151	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	500	60	TL	1439	1559	1499	FATEC-143	Kashimoto and Martins (2008)
152	C3	MT-IV-1	MT-IV-1	BRAZIL	PR	-235000	-52.5000	475	45	14C	1405	1611	1508	SI-1017	Chmyz (1969a); Stuckenrath and Mielke (1973)
153	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	490	60	TL	1449	1569	1509	FATEC-144	Kashimoto and Martins (2008)
154	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	480	60	TL	1459	1579	1519	FATEC-141	Kashimoto and Martins (2008)
155	C3	Itaquiraí 1	MS-PR-98	BRAZIL	MS	-23.5970	-54.0420	480	30	TL	1489	1549	1519	FATEC-196	Kashimoto and Martins (2008, 2009)
156	C3	Elevatório de Águas	PR-UV-16	BRAZIL	PR	-26.1670	-51.0000	500	45	14C	1398	1628	1513	SI-1015	Chmyz (1969b); Stuckenrath and Mielke (1973)
157	C3	RS-JC-57	----	BRAZIL	RS	-29.4132	-53.1463	470	50	14C	1405	1625	1515	Beta-181184	Soares (2004)
158	C3	Saltinho do Uruguai 3	ACH-SU-03-M2	BRAZIL	SC	-27.1402	-53.0406	470	40	14C	1410	1622	1516	Beta-226116	Caldarelli (2010)
159	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	460	55	TL	1484	1594	1539	FATEC-137	Kashimoto and Martins (2008)
160	C3	Corpus		ARGENTINA	MIS	-27.1100	-55.5017	459	43	14C	1415	1625	1520	AA-103647	Carbonera and Loponte (2018)
161	C3	Arenal Central		ARGENTINA	BA	-34.1803	-58,2505	480	30	14C	1419	1624	1522	Beta-662865	Loponte et al. (2025)

Table 1 (continued)

#	Cluster	SITE	CODE	COUNTRY	STATE	LAT	LONG	DATE	±1σ	M	AGE CE		Midpoint	LAB	REFERENCES
162	C3	Marisete da Costa	U-470	BRAZIL	RS	-27.4990	-51.8014	450	70	14C	1410	1635	1523	Beta-133973	Beta Report (1999)
163	C3	Uruguai 1	RS-URG-01	BRAZIL	RS	-27.1237	-53.0445	450	40	14C	1425	1625	1525	Beta-452033	Pereira Santos et al. (2021)
164	C3	Bento Prestes	RS-CM-11	BRAZIL	RS	-30.8450	-52.8920	445	40	14C	1429	1625	1527	SI-6402	Ribeiro et al. (1986)
165	C3	Candelária I		BRAZIL	RS	-29.6750	-52.7493	449	24	14C	1442	1615	1529	AA-108379	Loponte and Carbonera (2021)
166	C3	Arroyo Malo		ARGENTINA	BA	-343,263	-586,795	442	45	14C	1428	1627	1528	AA-103897	Bonomo et al. (2015)
167	C3	Santa Rita	RS-SR-342	BRAZIL	RS	-29.9810	-51.5330	440	60	14C	1425	1631	1528	Beta-129547	Hilbert (1999)
168	C3	Leandro Meier		BRAZIL	SC	-27.2014	-53.5019	450	20	14C	1445	1613	1529	UCIAMS 238990	Loponte et al. (2024a)
169	C3	Laranjal 1		BRAZIL	SC	-28.6200	-48.9379	440	40	14C	1433	1626	1530	Beta-262751	Milheira (2010)
170	C3	Morro Bonito 3		BRAZIL	SC	-28.6130	-48.9918	440	40	14C	1433	1626	1530	Beta-262755	Milheira (2010)
171	C3	482 A,8		ARGENTINA	COR	-27.5520	-57.1490	430	50	14C	1438	1629	1534	LP-734	Rodríguez (2009)
172	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	445	35	TL	1519	1589	1554	FATEC-140	Kashimoto and Martins (2008)
173	C3	Cem. A Paicarabí y Fredes		ARGENTINA	BA	-34.2090	-58.5680	421	45	14C	1445	1628	1537	AA-103896	Bonomo et al. (2015)
174	C3	Fazenda Dona Carlota 1	PR-FI-140	BRAZIL	PR	-25.2990	-54.3250	415	75	14C	1418	1655	1537	SI-5032	Chmyz (1983) in Noelli (1999–2000)
175	C3	483 1		ARGENTINA	COR	-27.5060	-56.7290	420	50	14C	1444	1630	1537	Beta-105251	Rodríguez (2009)
176	C3	Joaquim Bosquero	U 71 (Q1)	BRAZIL	SC	-27.5330	-51.7676	420	60	14C	1436	1640	1538	Beta-118376	Beta Report (1999)
177	C3	Arroyo La Glorieta		ARGENTINA	BA	-34.3460	-58.7440	416	41	14C	1448	1628	1538	AA-93216	Bonomo et al. (2015)
178	C3	Bataguaçú 4	MS-PD-06-BT4	BRAZIL	MS	-21.7030	-52.4310	415	40	TL	1544	1624	1584	FATEC-406	Kashimoto and Martins (2008)
179	C3	RS-T-114	RS-T-114	BRAZIL	RS	-29.2806	-52.1194	410	30	14C	1451	1627	1539	Beta-326927	Wolf (2012)
180	C3	RS-T-114	RS-T-114	BRAZIL	RS	-29.2806	-52.1194	410	30	14C	1451	1627	1539	Beta-388512	Schneider et al. (2017)
181	C3	Lagoa da Velhinha		BRAZIL	SC	-28.8655	-49.3077	410	30	14C	1451	1627	1539	Beta-696117	Campos and Perin (2023)
182	C3	Arenal Central		ARGENTINA	BA	-34.1803	-58.2505	410	30	14C	1451	1627	1539	Beta-663814	Loponte et al. (2025)
183	C3	Arenal Central		ARGENTINA	BA	-34.1803	-58.2505	410	40	14C	1451	1628	1540	LP-2543	Loponte et al. (2011)

Table 1 (continued)

#	Cluster	SITE	CODE	COUNTRY	STATE	LAT	LONG	DATE	±1σ	M	AGE CE		Midpoint	LAB	REFERENCES
184	C3	Corredeira Capela I	SC-U-3	BRAZIL	SC	-27.1785	-53.7190	405	15	14C	1456	1623	1540	UCIAMS 267510	Loponte et al. (2024a)
185	C3	SC-PP-118	U-478	BRAZIL	SC	-27.4888	-51.7952	405	15	14C	1456	1623	1540	UCIAMS 252944	Loponte et al. (2024a)
186	C3	519		ARGENTINA	COR	-27.3560	-56.1690	410	50	14C	1448	1632	1540	Beta-197133	Rodríguez (2009)
187	C3	El Arbolito-Arenal Central		ARGENTINA	BA	-34.1270	-58.2600	405	35	14C	1452	1628	1540	GrN-5156	Cigliano (1968)
188	C3	Arroyo Fredes		ARGENTINA	BA	-34.1863	-58.5527	402	40	14C	1454	1628	1541	AA-77309	Loponte et al. (2011)
189	C3	Saltinho do Uruguai 1	ACH-SU-01-C3	BRAZIL	SC	-27.1482	-53.0384	400	40	14C	1454	1628	1541	Beta-236424	Caldarelli (2010)
190	C3	Mondaí 1	SC-U-53	BRAZIL	SC	-27.1736	-53.4989	395	15	14C	1458	1624	1541	UCIAMS 252940	Loponte et al. (2024a)
191	C3	Aldeia Mirante da Lagoa	MLA	BRAZIL	SC	-28.8390	-49.2903	400	30	14C	1455	1628	1542	Beta-403217	Pereira Santos et al. (2016)
192	C3	Arenal Central		ARGENTINA	BA	-34.1803	-58.2505	400	30	14C	1455	1628	1542	Beta-663813	Loponte et al. (2025)
193	C3	Três Bocas 2		BRAZIL	RS	-27.5290	-54.6560	410	60	14C	1441	1643	1542	LP-1761	Costa Angrizani (2012)
194	C3	Linha Policial 7	ACH-LP-07	BRAZIL	SC	-27.1300	-53.0398	395	40	14C	1455	1630	1543	Gif13160/ SacA44482	Lourdeau et al. (2016)
195	C3	RS-T-117	RS-T-117	BRAZIL	RS	-29.2806	-52.1194	390	30	14C	1458	1628	1543	Beta-422490	Kreutz (2015)
196	C3	RS-T-132	RS-T-132	BRAZIL	RS	-29.1753	-52.1682	390	30	14C	1458	1628	1543	Beta-512708	Schneider (2019)
197	C3	Uruguai 1	RS-URG-01	BRAZIL	RS	-27.1237	-53.0445	390	30	14C	1458	1628	1543	Beta-421977	Pereira Santos (2018)
198	C3	Uruguai 1	RS-URG-01	BRAZIL	RS	-27.1237	-53.0445	390	25	14C	1458	1628	1543	GifA-19122	Carbonera et al. (2024)
199	C3	Llamarada 1		ARGENTINA	COR	-28.3190	-58.0820	400	50	14C	1451	1636	1544	Beta-41939	Mujica (1995b, c)
200	C3	SC-CH-161	SC-CH-161	BRAZIL	SC	-27.2396	-52.7376	385	15	14C	1461	1627	1544	UCIAMS 267426	Loponte et al. (2024a)
201	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	435	50	TL	1514	1614	1564	FATEC-160	Kashimoto and Martins (2008)
202	C3	Ponte Alta 1	BI21 CLM-ST	BRAZIL	PR	-25.5621	-53.5860	380	30	14C	1461	1630	1546	Beta-518755	Novasco et al. (2021)
203	C3	Mãe Luzia 3	SC-ARA-010	BRAZIL	SC	-28.8911	-49.3486	380	30	14C	1461	1630	1546	Beta-403218	Pereira Santos et al. (2016)
204	C3	Silvério Barbian	SC-U-6	BRAZIL	SC	-27.1810	-53.7195	380	15	14C	1463	1628	1546	UCIAMS 267509	Loponte et al. (2024a)

Table 1 (continued)

#	Cluster	SITE	CODE	COUNTRY	STATE	LAT	LONG	DATE	±1σ	M	AGE CE		Midpoint	LAB	REFERENCES
205	C3	Fazenda Dona Carlota 4	PR-FI-142	BRAZIL	PR	-25.5450	-54.5740	395	60	14C	1447	1647	1547	SI-5034	Chmyz (1983) in Noelli (1999–2000)
206	C3	Rio Pardo 4	MS-PD-04	BRAZIL	MS	-22.1860	-52.7850	432	32	TL	1535	1599	1567	FATEC-187	Kashimoto and Martins (2008)
207	C3	Itajubá 1		BRAZIL	RS	-27.5440	-54.6680	390	60	14C	1448	1649	1549	LP-1751	Costa Angrizani (2012)
208	C3	511 C		ARGENTINA	COR	-27.6370	-56.6150	390	60	14C	1448	1649	1549	Beta-197130	Rodríguez (2009)
209	C3	Passo Fundo	RS-M-16	BRAZIL	RS	-29.9330	-50.2170	520	200	14C	1160	1983	1572	SI-410	Miller (1967); Stuckenrath and Mielke (1970)
210	C3	516 C		ARGENTINA	COR	-27.4150	-56.2690	380	50	14C	1456	1643	1550	Beta-197132	Rodríguez (2009)
211	C3	Jaboticabeira 8 A 1, N 1		BRAZIL	SC	-28.5765	-48.9794	370	30	14C	1463	1636	1550	Beta- 466821	Schwengber et al. (2017)
212	C3	RS-T-101	RS-T-101	BRAZIL	RS	-29.2554	-52.1585	370	30	14C	1463	1636	1550	Beta-326926	Wolf (2012)
213	C3	RS-T-132	RS-T-132	BRAZIL	RS	-29.1753	-52.1682	370	30	14C	1463	1636	1550	Beta-472012	Schneider (2019)
214	C3	Arroyo Fredes		ARGENTINA	BA	-34.1863	-58.5527	370	50	14C	1458	1646	1552	LP-1428	Loponte et al. (2011)
215	C3	Saltinho do Uruguai 1	ACH-SU-01-C3	BRAZIL	SC	-27.1482	-53.0384	360	40	14C	1463	1646	1555	Beta-236426	Caldarelli (2010)
216	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	425	25	TL	1549	1599	1574	FATEC-183	Kashimoto and Martins (2008)
217	C3	Llamarada 1		ARGENTINA	COR	-28.3190	-58.0820	370	60	14C	1451	1662	1557	Beta-41943	Mujica (1995b, c)
218	C3	Pedro Ademar da Silva	U-454	BRAZIL	SC	-27.5069	-51.7980	370	60	14C	1451	1662	1557	Beta-149067	Beta Report (1999)
219	C3	Alto Alegre 3	ALP-AA-03	BRAZIL	RS	-27.1494	-53.0624	375	15	14C	1485	1629	1557	UCIAMS 267427	Loponte et al. (2024a)
220	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	420	50	TL	1529	1629	1579	FATEC-157	Kashimoto and Martins (2008)
221	C3	Arroio Vitória II	SC-U-26	BRAZIL	SC	-27.1833	-53.7079	370	15	14C	1496	1630	1563	UCIAMS 252939	Loponte et al. (2024a)
222	C3	RS-03	RS-03	BRAZIL	RS	-29.1499	-51.9015	360	30	14C	1483	1644	1564	Beta-422489	Kreutz (2015)
223	C3	Arenal Central		ARGENTINA	BA	-34.1803	-58.2505	360	30	14C	1483	1644	1564	Beta-662866	Loponte et al. (2025)
224	C3	Valdemar Picolli		BRAZIL	SC	-27.1852	-53.1827	365	15	14C	1498	1633	1566	UCIAMS 252938	Loponte et al. (2024a)
225	C3	Jaboticabeira 8 - A 1, N 5		BRAZIL	SC	-28.5765	-48.9794	350	30	14C	1487	1648	1568	Beta-466822	Schwengber et al. (2017)

Table 1 (continued)

#	Cluster	SITE	CODE	COUNTRY	STATE	LAT	LONG	DATE	±1σ	M	AGE CE		Midpoint	LAB	REFERENCES
226	C3	Mãe Luzia 1	SC-ARA-008	BRAZIL	SC	-28.8958	-49.3535	350	30	14C	1487	1648	1568	Beta-366850	Pereira Santos et al. (2016)
227	C3	RS-T-114	RS-T-114	BRAZIL	RS	-29.2806	-52.1194	350	30	14C	1487	1648	1568	Beta-388513	Schneider et al. (2017)
228	C3	Juvenil Mattos	U-391	BRAZIL	SC	-27.5196	-51.7880	360	15	14C	1500	1636	1568	UCIAMS 252942	Loponte et al. (2024a)
229	C3	Rio Taquari 1	MS-PR-46	BRAZIL	MS	-21.4170	-52.0188	410	40	TL	1549	1629	1589	FATEC-107	Kashimoto and Martins (2008)
230	C3	Uruguai 1	RS-URG-01	BRAZIL	RS	-27.1237	-53.0445	350	25	14C	1499	1646	1573	GifA22312/ECHo-5136.1.1	Carbonera et al. (2024)
231	C3	Jaboticabeira 8 - A3, N1		BRAZIL	SC	-28.5765	-48.9794	340	30	14C	1497	1653	1575	Beta-466824	Schwengber et al. (2017)
232	C3	Mãe Luzia 1	SC-ARA-008	BRAZIL	SC	-28.8958	-49.3535	340	30	14C	1497	1653	1575	Beta-366854	Pereira Santos et al. (2016)
233	C3	Mãe Luzia 1	SC-ARA-008	BRAZIL	SC	-28.8958	-49.3535	340	30	14C	1497	1653	1575	Beta-366853	Pereira Santos et al. (2016)
234	C3	Arenal Central		ARGENTINA	BA	-34.1803	-58.2505	340	30	14C	1497	1653	1575	Beta-663812	Loponte et al. (2025)
235	C3	Osni Moraes	U-458	BRAZIL	SC	-27.5265	-51.8009	330	15	14C	1508	1648	1578	UCIAMS 252943	Loponte et al. (2024a)
236	C3	Uruguai 1	RS-URG-01	BRAZIL	RS	-27.1237	-53.0445	330	25	14C	1504	1653	1579	GifA-19120/ECHo-2964	Carbonera et al. (2024)
237	C3	Uruguai 1	RS-URG-01	BRAZIL	RS	-27.1237	-53.0445	330	25	14C	1504	1653	1579	GifA-19121/ECHo-2965	Carbonera et al. (2024)
238	C3	Punta Negra		URUGUAY	RN	-33.1057	-58.2406	330	30	14C	1501	1661	1581	Beta-434382	Gascue et al. (2019)
239	C3	RS 6 Estádio Aimoré		BRAZIL	RS			330	30	14C	1501	1661	1581	Beta-411919	Schmitz et al. (2019)
240	C3	Estância Velha 1		BRAZIL	RS	-29.6266	-51.1932	320	30	14C	1503	1665	1584	Beta-431945	Schmitz et al. (2019)
241	C3	Mãe Luzia 1	SC-ARA-008	BRAZIL	SC	-28.8958	-49.3535	320	30	14C	1503	1665	1584	Beta-366851	Pereira Santos et al. (2016)
242	C3	Uruguai 1	RS-URG-01	BRAZIL	RS	-27.1237	-53.0445	310	25	14C	1507	1665	1586	GifA-19123/ECHo-2966	Carbonera et al. (2024)
243	C3	Alto Paraná 8	MS-PR-35-AP8	BRAZIL	MS	-21.5410	-52.1060	390	40	TL	1569	1649	1609	FATEC-98	Kashimoto and Martins (2008)
244	C3	Elias Dal Prá	RS-MJ-50	BRAZIL	RS	-29.6890	-53.5500	354	105	14C	1415	1814	1615	SI-818	Brochado (1971); Stuckenrath and Mielke (1973)

Table 1 (continued)

#	Cluster	SITE	CODE	COUNTRY	STATE	LAT	LONG	DATE	±1σ	M	AGE CE		Midpoint	LAB	REFERENCES
245	C3	Rio Taquari 4	MS-PR-48	BRAZIL	MS	-21.4170	-52.0188	380	40	TL	1579	1659	1619	FATEC-108	Kashimoto and Martins (2009)
246	C3	Córrego São Lourenço 1	MS-PR-26	BRAZIL	MS	-22.0180	-52.3770	380	40	TL	1579	1659	1619	FATEC-122	Kashimoto and Martins (2008)
247	C3	Ribeirão Quiteroizinho 1	MS-PR-18	BRAZIL	MS	-22.1130	-52.4930	380	40	TL	1579	1659 and	1619	FATEC-106	Kashimoto and Martins (2008)
248	C3	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	375	45	TL	1579	1669	1624	FATEC-151	Kashimoto and Martins (2008)
249	C3	Lagoa Ariranha 1	MS-PR-22	BRAZIL	MS	-22.0970	-52.3990	370	20	TL	1609	1649	1629	FATEC-185	Kashimoto and Martins (2008)
250	C3	482 A, 11		ARGENTINA	COR	-27.5520	-57.1490	360	60	14C	1451	1791	1621	Beta-105253	Rodríguez (2009)
251	C3	Lagoa Seca	PR-FI-118	BRAZIL	PR	-25.4630	-54.5090	340	60	14C	1454	1797	1626	SI-5023	Chmyz (1983) in Noelli (1999–2000)
252	C4	482 A, 8		ARGENTINA	COR	-27.5520	-57.1490	330	50	14C	1459	1796	1628	LP-750	Rodríguez (1997, 2009)
253	C4	PS-02-Camping		BRAZIL	RS	-31.7239	-52.1957	330	50	14C	1459	1796	1628	Beta-234205	Milheira (2008, 2014)
254	C4	Saltinho do Uruguai 3	ACH-SU-03-M2	BRAZIL	SC	-27.1402	-53.0406	320	60	14C	1459	1800	1630	Beta -226115	Caldarelli (2010)
255	C4	Lagoa do Custódio 1	MS-IV-08	BRAZIL	MS	-22.3844	-52.8688	350	40	TL	1609	1689	1649	FATEC-136	Kashimoto and Martins (2008)
256	C4	Córrego Caraguatá 2	MS-PR-28	BRAZIL	MS	-21.9400	-52.4210	350	35	TL	1614	1684	1649	FATEC-116	Kashimoto and Martins (2008)
257	C4	Ribeirão Quiteroí 1	MS-PR-08	BRAZIL	MS	-22.2070	-52.6280	350	30	TL	1619	1679	1649	FATEC-96	Kashimoto and Martins (2008)
258	C4	511 E		ARGENTINA	COR	-27.6370	-56.6150	310	50	14C	1465	1800	1633	Beta-197131	Rodríguez (2009)
259	C4	484 A, 4		ARGENTINA	COR	-27.5200	-56.7300	300	50	14C	1485	1805	1645	Beta-105250	Rodríguez (2009)
260	C4	482 C, 2		ARGENTINA	COR	-27.5520	-57.1490	300	50	14C	1485	1805	1645	Beta-105248	Rodríguez (2009)
261	C4	Uruguai 1	RS-URG-01	BRAZIL	RS	-27.1237	-53.0445	310	30	14C	1504	1793	1649	Beta-421976	Pereira Santos (2018)
262	C4	RS-T-114	RS-T-114	BRAZIL	RS	-29.2806	-52.1194	300	30	14C	1506	1797	1652	Beta-303993	Wolf (2012)
263	C4	RS-MJ-50	RS-MJ-50	BRAZIL	RS	-29.6417	-53.7956	345	105	14C	1424	1882	1653	SI-818	Schmitz Ms.

Table 1 (continued)

#	Cluster	SITE	CODE	COUNTRY	STATE	LAT	LONG	DATE	±1σ	M	AGE CE		Midpoint	LAB	REFERENCES
264	C4	RS-T-132	RS-T-132	BRAZIL	RS	-29.1753	-52.1682	290	30	14C	1508	1799	1654	Beta-472011	Schneider (2019)
265	C4	Armandio Vortmann	011	BRAZIL	SC	-27.2567	-52.3804	358	17	TL	1639	1673	1656	-	Carbonera (2014)
266	C4	Ribeirão Quiteroí 1	MS-PR-08	BRAZIL	MS	-22.2070	-52.6280	320	35	TL	1644	1714	1679	FATEC-94	Kashimoto and Martins (2008)
267	C4	Poço Grande		BRAZIL	SC	-26.4446	-48.8438	340	35	TL	1629	1699	1664	-	da Bandeira (2004)
268	C4	Arroyo Fredes		ARGENTINA	BA	-34.1863	-58.5527	251	35	14C	1517	1810	1664	LTL33020	Loponte et al. (2024b)
269	C4	Valdemar Stensseler	009	BRAZIL	SC	-36.4055	-69.8504	344	33	TL	1637	1703	1670	-	Carbonera (2014)
270	C4	Rancho Leôn-cio 2	PR-FL-5	BRAZIL	PR	-23.5000	-52.5000	300	115	14C	1451	1895	1673	SI-693	Chmyz (1969a); Stuckenrath and Mielke (1973)
271	C4	Ernesto Kolbow		BRAZIL	SC	-27.2625	-52.3793	340	9	TL	1665	1683	1674	-	Loponte et al. (2024a)
272	C4	Otto Aigner 1	013	BRAZIL	SC	-27.2499	-52.3924	335	16	TL	1663	1695	1679	-	Carbonera (2014)
273	C4	Lagoa da Porteira 1	RS-LC-80	BRAZIL	RS	-30.4247	-50.5576	280	50	14C	1497	1876	1687	Beta-202366	Schmitz and Sandrin (2009)
274	C4	Eri Rampel-lotto	RS-MJ-71	BRAZIL	RS	-29.5320	-53.5360	265	90	14C	1486	1896	1691	SI-2199	Brochado (1971, 1984)
275	C4	MT-IV-1	MT-IV-1	BRAZIL	PR	-23.5000	-52.5000	260	70	14C	1500	1895	1698	SI-1016	Chmyz (1969a), Stuckenrath and Mielke (1973)
276	C4	Ribeirão Quiteroí 1	MS-PR-08	BRAZIL	MS	-22.2070	-52.6280	300	50	TL	1649	1749	1699	FATEC-95	Kashimoto and Martins (2008)
277	C4	511 D		ARGENTINA	COR	-27.6370	-56.6150	240	50	14C	1513	1894	1704	Beta-105252	Rodríguez (2009)
278	C4	Silvino Predi-ger I	010	BRAZIL	SC	-27.2544	-52.3759	309	13	TL	1692	1718	1705	-	Carbonera (2014)
279	C4	Córrego São Lourenço 1	MS-PR-26	BRAZIL	MS	-22.0180	-52.3770	290	30	TL	1679	1739	1709	FATEC-123	Kashimoto and Martins (2008)
280	C4	RS-T-114	RS-T-114	BRAZIL	RS	-29.2806	-52.1194	260	30	14C	1630	1806	1718	Beta-388514	Schneider et al. (2017)
281	C4	Ribeirão Taquari 2	MS-PR-46	BRAZIL	MS	-21.2090	-51.8780	280	15	TL	1704	1734	1719	FATEC-192	Kashimoto and Martins (2008)

Table 1 (continued)

#	Cluster	SITE	CODE	COUNTRY	STATE	LAT	LONG	DATE	±1σ	M	AGE CE		Midpoint	LAB	REFERENCES
282	C4	Santa Rita do Pardo 2	MS-PD-07-SR2	BRAZIL	MS	-21.7030	-52.5000	275	20	TL	1704	1744	1724	FATEC-188	Kashimoto and Martins (2008)
283	C4	João A. Guarantier	SC-U-54*	BRAZIL	SC	-27.0803	-53.0396	250	90	14C	1500	1950	1725	SI-546	Piazza (1969); Stuckenrath and Mielke (1972)
284	C4	Taquapelagai	PR-FI-97	BRAZIL	PR	-25.5010	-54.0300	255	80	14C	1502	1950	1726	SI-5017	Chmyz (1983) in Noelli (1999–2000)
285	C4	Bataguaçú 4	MS-PD-06-BT4	BRAZIL	MS	-21.7030	-52.4310	240	30	14C	1643	1809	1726	Gif-10038	Kashimoto and Martins (2008)
286	C4	RS-T-114	RS-T-114	BRAZIL	RS	-29.2806	-52.1194	240	30	14C	1643	1809	1726	Beta-367375	Schneider et al. (2017)
287	C4	Uruguai 1	RS-URG-01	BRAZIL	RS	-27.1237	-53.0445	240	30	14C	1643	1809	1726	Beta-421973	Pereira Santos et al. (2021)
288	C4	Rio Condor 3	PR-FL-13	BRAZIL	PR	-23.5000	-52.5000	135	120	14C	1510	1950	1730	SI-698	Chmyz (1969a), Stuckenrath and Mielke (1973)
289	C4	Aurélio C. Bernardes	RS-MJ-90	BRAZIL	RS	-29.7290	-52.6810	220	85	14C	1510	1950	1730	SI-2202	Brochado (1971, 1984)
290	C4	Foz do Bela Vista 1	PR-FI-22	BRAZIL	PR	-25.3900	-54.3560	230	80	14C	1509	1950	1730	SI-5015	Chmyz (1983) in Noelli (1999–2000)
291	C4	Antônio Calderolli	U-467	BRAZIL	SC	-27.5145	-51.8212	210	80	14C	1512	1950	1731	Beta-149068	Beta Report (1999)
292	C4	Lagoa Seca	PR-FI-118	BRAZIL	PR	-25.4630	-54.5090	205	80	14C	1512	1950	1731	SI-5022	Chmyz (1983) in Noelli (1999–2000)
293	C4	Adolfo Schenkel	RS-C-63	BRAZIL	RS	-29.3720	-51.5650	190	85	14C	1513	1950	1732	SI-1197	Ribeiro (1968, 1974); Rogge (2005)
294	C4	Bataguaçú 4	MS-PD-06 BT4	BRAZIL	MS	-21.7030	-52.4310	250	25	TL	1724	1774	1749	FATEC-405	Kashimoto and Martins (2008)
295	C4	Córrego Azul 1	MS-PR-41	BRAZIL	MS	-21.4280	-52.0180	245	15	TL	1739	1769	1754	FATEC-191	Kashimoto and Martins (2008)
296	C4	Ribeirão Quiteroí 6	MS-PR-13	BRAZIL	MS	-22.1360	-52.7030	239	10	TL	1750	1770	1760	FATEC-184	Kashimoto and Martins (2009)
297	C4	Escola velha	U-377	BRAZIL	SC	-27.4894	-51.7694	230	50	14C	1629	1896	1763	Beta-149069	Beta Report (1999)

Table 1 (continued)

#	Cluster	SITE	CODE	COUNTRY	STATE	LAT	LONG	DATE	±1σ	M	AGE CE		Midpoint	LAB	REFERENCES
298	C4	Jaboticaba 1	RS-VZ-41*	BRAZIL	RS	-21.1670	-53.7330	225	50	14C	1634	1895	1765	SI-701	Miller (1969); Stuckenrath and Mielke (1973)
299	C4	Trovoada 1	----	BRAZIL	RS	-29.6908	-50.0149	210	30	14C	1656	1882	1769	Beta-621210	Campos et al. (2023)
300	C4	SC-CH-158	SC-CH-158	BRAZIL	SC	-27.2531	-52.7041	200	30	14C	1664	1890	1777	Beta-308753	De Masi (2012)
301	C4	RS-NO-161	RS-NO-161	BRAZIL	SC	-27.2146	-52.7678	195	30	14C	1666	1891	1779	Beta-308749	De Masi (2012)
302	C4	Porto Estamata	PR-FI-98	BRAZIL	PR	-25.1720	-54.3880	190	75	14C	1632	1950	1791	SI-5018	Chmyz (1983) in Noelli (1999–2000)
303	C4	Elias Dal Prá	RS-MJ-50	BRAZIL	RS	-29.6890	-53.5500	110	100	14C	1654	1950	1802	SI-817	Brochado (1969); Stuckenrath and Mielke (1973)
304	C4	MT-IV-1	MT-IV-1	BRAZIL	PR	-23.5000	-52.5000	180	60	14C	1666	1950	1808	SI-1018	Chmyz (1969a); Stuckenrath and Mielke (1973)
305	C4	Reinaldo Kappel	RS-RP-140	BRAZIL	RS	-29.7290	-52.6810	180	60	14C	1666	1950	1808	SI-3523	Ribeiro (1991)
306	C4	RS-VZ-44	RS-VZ-44	BRAZIL	RS	-27.3018	-54.1434	160	70	14C	1667	1950	1809	-	Miller (2009)
307	C4	João B. Cantarelli	RS-MJ-42	BRAZIL	RS	-29.8240	-53.3830	130	105	14C	1673	1950	1812	SI-815	Brochado (1969); Stuckenrath and Mielke (1973)
308	C4	MT-IV-2	MT-IV-2	BRAZIL	PR	-23.6670	-53.3330	110	60	14C	1673	1950	1812	SI-1019	Chmyz (1969a), Stuckenrath and Mielke (1973)
309	C4	Saltinho do Uruguai 2	ACH-SU-02	BRAZIL	SC	-29.8260	69.9578	110	40	14C	1690	1950	1820	Beta-236427	Caldarelli (2010)
310	C4	Linha Policial 7	ACH-LP-07	BRAZIL	SC	-27.1300	-53.0398	115	30	14C	1697	1950	1824	Gif13119/ SacA40196	Lourdeau et al. (2016)
311	C4	Martin Aigner	SC-XII	BRAZIL	SC	-27.2524	-52.3847	110	15	14C	1709	1950	1830	UCIAMS 267424	Loponte et al. (2024a)
312	C4	Linha Policial 7	ACH-LP-07	BRAZIL	SC	-27.1300	-53.0398	105	30	14C	1698	1950	1824	Gif13118/ SacA40195	Lourdeau et al. (2016)
313	C4	RS-T-132	RS-T-132	BRAZIL	RS	-29.1753	-52.1682	100	30	14C	1698	1950	1824	Beta-512707	Schneider (2019)

modifications for this study based on updated analyses of the locations of various sites (e.g., Cerezer 2017; Loponte et al. 2024a, b). This refinement of site locations remains a work in progress, as in several cases, the original geographical coordinates rely on unpublished original data found in handwritten reports. Many sites have multiple sets of coordinates in the original literature (particularly from CRM projects), corresponding to their different sectors. For simplicity, we have selected only one set of coordinates for each site.

Data clustering

Since radiocarbon and thermoluminescence determinations provide chronological ranges, relying on midpoint values and grouping them based on heuristic rules can result in conceptual errors in clustering. Therefore, we utilized the calibrated ranges (lower and upper limits for each date) combined with statistical tools, to perform the clustering analysis.

The analysis of the distribution of the calibrated ranges were conducted by applying K-means analysis through Silhouette Coefficient (SCA), Hierarchical Cluster Analysis (HCA), Principal Components Analysis (PCA), and Summed Probability Distributions (SPD). The first method tends to group data based on their centroids, significantly reducing sample variability and producing results with moderate to low dispersion (Liu et al. 2008; Rousseeuw 1987). Meanwhile, HCA applies more flexible criteria, primarily considering ranges, often resulting in a greater number of groups and promoting higher data dispersion. PCA was employed as a supplementary tool to analyze data dispersion and clustering along both components, providing insights into potential clustering within the SCA-derived groups. These three methods are complementary, offering diverse perspectives for evaluating data clustering. Furthermore, they can be compared with the Summed probability distribution (SPD), whose peaks and valleys not only assist in grouping ages but have also been partially associated with population density (Attenbrow and Hiscock 2015; Crema and Bevan 2021a, b; Hiscock and Attenbrow 2016; Smith 2016; Williams 2012). To avoid oversampling, we generated a second SPD graph by calculating the Bayesian average for dates originating from the same site with overlapping calibrated ranges. Additionally, we applied a Gaussian filter with a high sigma ($\sigma = 10$) to smooth minor fluctuations and highlight general trends.

Some issues commonly associated with analyzing large datasets within the SPD framework are not relevant for the series examined in this study or have a lesser impact. These biases include taphonomic loss of the datable record or variation resulting from the use of different calibration curves (Williams 2012). Other biases, such as sample sizes, are inherent to any archaeological analysis based on sampling, which is why the results presented here are probabilistic. As we will observe, all data clustering methods produce broadly consistent results, with minor variations in nuance.

Another secondary issue relates reports to some ages with high uncertainties, typically with errors ≥ 100 years, which hinder their correct inclusion within the clusters. While some authors facing similar problems in other regions of the world discard them (e.g., Kennett et al. 2014; Martínez-Grau et al. 2021), in this coarse-grained study this impact is minimum.

Quality and assignation of radiocarbon and TL ages

Before conducting the clustering analyses, we thoroughly reviewed the Guaraní chronological databases available in the literature, focusing on studies that have previously addressed the Guaraní expansion, and with particular attention to the reliability of key ages. This review identified several issues. The first involves the attribution of certain ages to Guaraní occupations that, in reality, do not correspond to Guaraní sites or layers. These data were therefore excluded, a necessary step as they are unrelated to the phenomenon under study—namely, the Guaraní expansion. The second issue concerns errors in the assignment of radiocarbon or TL determinations; although the dates are associated with Guaraní sites, the site names or ages were either inaccurately recorded or misattributed. Below, we provide significant examples of both types of issues, while a more comprehensive discussion is presented in the Supplementary Text.

As a first example, we highlight the Lagoa 1 site (Ariranha – MS-PR-22), where a radiocarbon age of 1800 ± 40 ^{14}C years BP (code Gif-11073) was obtained by Martins et al. (1999) from a hunter-gatherer occupation (see also Kashimoto and Martins 2008, 2009). However, this age was attributed to a Guaraní occupation in the study by Bonomo et al. (2015: 58). In fact, the Guaraní layer at this site is dated to 370 ± 20 years BP (TL), corresponding to laboratory code Fatec-185 (Martins et al. 1999: 83–84; Kashimoto and Martins 2008: 161; Kashimoto and Martins 2009: 145–146; Kashimoto, pers. comm.; see Supplementary Text). A similar issue arises with the radiocarbon age of 900 ± 50 ^{14}C years BP from site U-368 (code Beta-118377), associated with a hunter-gatherer occupation in the upper Uruguay River valley (Domiks 2001; Monticelli, pers. comm.), but erroneously attributed to the Guaraní site SC-U-71 in previous databases (e.g., Noelli 1999–2000; Bonomo et al. 2015, among others). In reality, SC-U-71 (or U-71) is indeed a Guaraní site, but it has two distinct radiocarbon dates with laboratory codes Beta-118375 and Beta-118376 (Loponte et al. 2024a, b; Table 1 and Supplementary Text).

Another significant example concerns the age 2010 ± 75 ^{14}C years BP (SI–5028), attributed to a Guaraní occupation at the Fazenda Dona Carlota site (PR-FI-140) by Noelli (1999–2000) Bonomo et al. (2015) and Noelli and Corrêa

(2016) among others. However, Chmyz, who excavated this disturbed site, rejects this attribution, considering that only a second radiocarbon age of 745 ± 75 ^{14}C years BP obtained from this layer accurately reflects the Guaraní occupation. The recovered materials correspond to the "Ibirajé phase", which has similar radiocarbon ages to the latter throughout the region (Chmyz 1983; pers. comm.).

More extensive errors involve multiple ages, such as those attributed to the Brasilândia 11 site. All ages from this site were obtained and published by Martins et al. (1999) and Kashimoto and Martins (2008, 2009; Kashimoto, pers. comm.) attributed to unidentified pottery occupations. However, they were erroneously assigned to Guaraní occupations at the Ilha Verde 2 site (e.g., Bonomo et al. 2015:59).

The exclusion or reassignment of these determinations is not due to their inherent quality or because they do not fit a specific model, as no model had been constructed at this stage of the analysis. On the contrary, these exclusions and corrections are mandatory because they simply address errors in attribution. It is important to emphasize that these dates were excluded prior to the clustering analysis. Therefore, no data were removed to fit an existing model; instead, the model presented here emerged after refining the database, resulting in a robust framework. This approach allows for future expansion as new, consistently obtained ages are incorporated, following best practices established in other regions for managing reliable chronological databases.

Finally, there is another small group of determinations that has raised concerns within the archaeological community regarding their reliability. These are often extreme outliers that lack the necessary contextual data for robust chronological analysis, particularly when used to establish the earliest Guaraní occupations in certain regions. For example, one case involves the radiocarbon age from the San Miguel II site in Corrientes, Argentina, dated to 1860 ± 50 ^{14}C years BP, originating from an archaeological context briefly described by Mujica (1995a, b). While this result is potentially relevant to discussions of Guaraní expansion, it conflicts with regional patterns and creates an unexplained Guaraní archaeological gap of 1000 radiocarbon years, as the other 22 radiocarbon determinations available for this area are all later than ~ 800 ^{14}C years BP. This raises reasonable doubts about its assignment to a Guaraní occupation or the possibility of sample contamination. Cases like this underscore the importance of rigorous validation of chronological determination, especially when they serve as key chronological benchmarks (see Supplementary Text for further examples). Samples of uncertain origin or questionable quality were also excluded prior to generating the spatiotemporal distribution model presented here, ensuring that the database was not adjusted *ad hoc* to fit any pre-existing model (see Supplementary Text for more details).

Results

The earliest sites and the initial colonization area

The new Guaraní chronological database presented in Table 1 (Sect. "Materials and methods") includes 313 ages, with four standing out due to their early range (160–650 CE). Two of the earliest ages (#1 and #2 in Table 1) are TL-based. The first corresponds to the Ragil site, dated to 1668 ± 170 years BP (TL 168–508 CE). Unfortunately, this highly impacted site has only a single TL age with an uncertainty of approximately 10%, indicating low reliability. Its most recent calibrated range extends to ~ 500 CE, aligning with more reliable determinations from the area (see below). While this data requires confirmation, we provisionally consider it here.

The second early age corresponds to a TL determination of 1519 ± 200 years BP (288–688 CE) from the João Batista site (without a laboratory code). This determination also has high uncertainty, extending its range up to ~ 700 CE. Since regional data support the presence of Guaraní occupations after 500 CE, we will initially consider it; however, more rigorous and higher-quality analyses are needed to fully confirm this early occupation of the site.

The other two early ages correspond to radiocarbon determination obtained from the Lagoa Seca and Boreví sites, ranging from 343 to 650 CE, with the most probable chronological range between 361—602 CE (93.8%), and 410—650 CE (94.3%) respectively (midpoint ~ 500 CE) (Fig. 4). These four early data reflect a weak archaeological signal of the initial Guaraní occupation of the upper basin, close to the tri-state border with Mato Grosso do Sul State and the Republic of Paraguay (Fig. 5), which we will use as a reference point to calculate expansion rates (Sect. "Migration rates"). The Guaraní record in these early sites seems to appear with all its typical characteristics already fully formed. There is no clear evidence in the local record suggesting a prior stage of development for these contexts. Instead, an allochthonous origin appears more likely, considering the record from southwestern Amazonia and linguistic data (Sects. "Introduction" and "The dispersal of the Tupi-Guaraní").

General trends of the Guaraní expansion

The distribution of all Guaraní ages listed in Table 1 (Sect. "Materials and methods") exhibits a north-to-south dispersal pattern, grouped into three major chronological phases (Fig. 6). The first phase corresponds to what appears to be the initial colonization, which began around ~ 500 ± 100 CE in the upper La Plata basin, including the states of Mato Grosso do Sul, São Paulo, and Paraná.

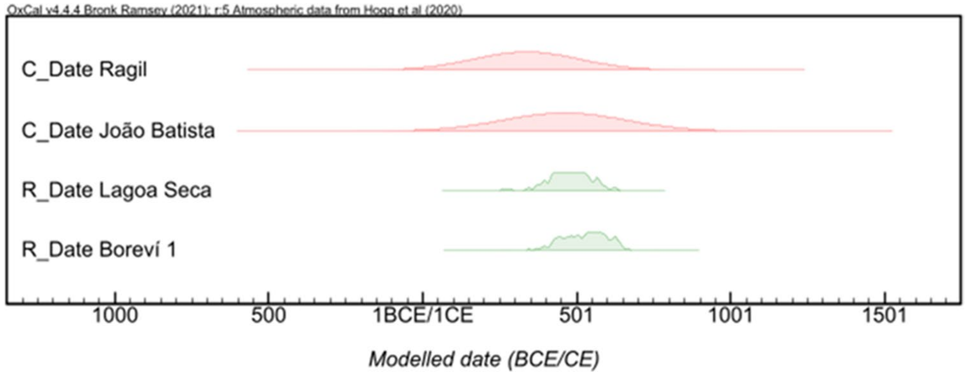

Fig. 4 Chronological ranges of the four earliest ages. TL ages are shown in red, and ^{14}C ages in green

Fig. 5 Distribution of the earliest Guaraní sites in red dots detected in the La Plata basin (sites #1 to #4 from Table 1). The white triangle marks the center of minimum distance among them (based on www.geomidpoint.com)

Following the first step, Fig. 6 shows a second geo-chronological phase beginning from around ~ 800 ± 100 CE, based on the earliest available ages for the states of Santa Catarina and Rio Grande do Sul, towards the south and southeast of the previous step I. This development also aligns with a slight increment in the number of sites, potentially indicating a new phase in the colonization process (Sect. "Cluster analysis"). In this second block, the province of Misiones is included, though it has only a few radiocarbon dates (Table 1), with the oldest ones aligning with the start of this phase. However, since the Lagoa Seca and Boreví sites, which are assigned to the first block are located near its border, additional sampling could eventually lead to Misiones being included in the first phase.

Finally, around ~ 1300 ± 100 CE, a third geo-chronological phase emerges, covering the southern territories including Corrientes, Uruguay and Buenos Aires, as depicted in Fig. 6 (Uruguay and Entre Ríos are included in Buenos Aires block). This new step also coincides chronologically with a significant rise in the number of sites across all regions, a trend we will delve into in subsequent sections.

Within this final block is included the age #63 (Table 1) corresponding to the Arroyo Fredes site (1229–1423 CE, midpoint 1326 CE). This age presents the older Guaraní site in the Paraná Delta, which is the southern extreme of the Guaraní expansion.[2] Multiple elements make this radiocarbon age robust, such as being obtained from an individual buried in a Guaraní site, within a Guaraní urn, and yielding typical isotopic values of a Guaraní diet. The dated bone had a suitable collagen yield for AMS radiocarbon dating (> 1%) without evidence of diagenesis (C/N atomic ratio 2.9; Loponte 2020; Loponte and Acosta 2003). Additionally,

[2] Although some maps of the Guaraní dispersal show areas further south of the Paraná Delta, these sites do not correspond to Guaraní settlements, but rather reflect the spread of Guaraní pottery in hunter-gatherer contexts.

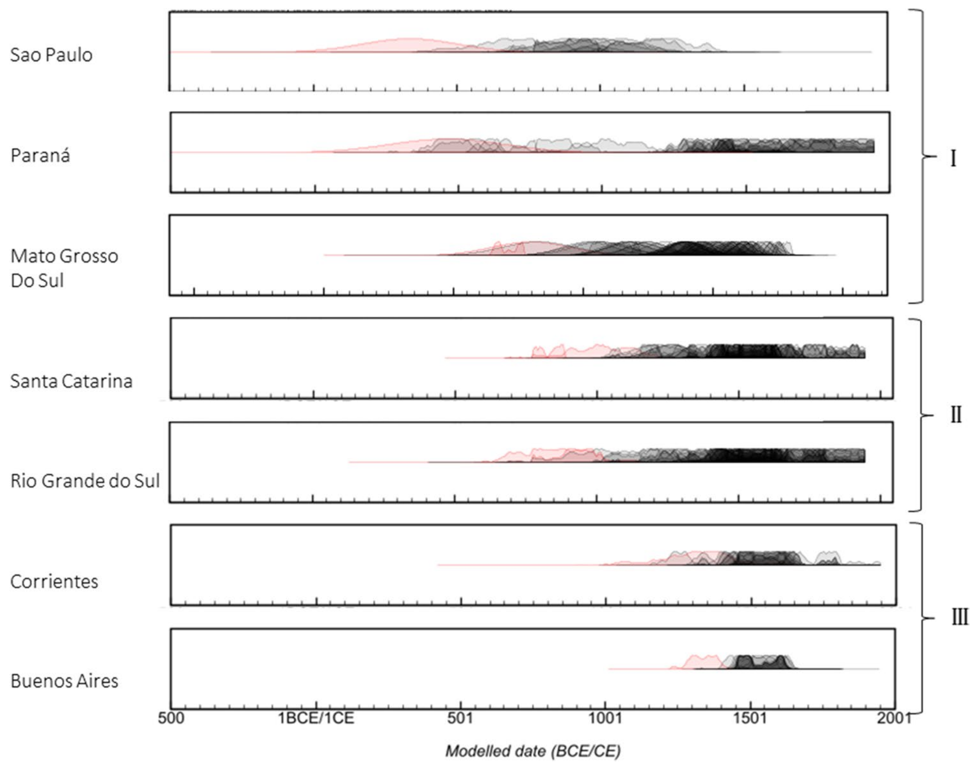

Fig. 6 Stacked plots of the ages (^{14}C + TL) by state/province. The first age for each state/province is highlighted in red. On the right, the three territorial blocks of the expansion are identified as I, II and III

this site is located 370 km downstream along the Uruguay River from the Guaraní site Isla de Arriba—Aruera (data #47, Table 1), dated to 1028–1381 CE (midpoint 1205 CE), whose chronological range is slightly older and consistent with the expansion along the Uruguay River. While Isla de Arriba—Aruera also has previous occupations of hunter-gatherers, this age was obtained from an individual buried in a Guaraní urn whose $\delta^{13}C$ value indicates consistent consumption of maize, in line with the Guaraní diet (Bracco et al. 2000).

The three main steps or geo-chronological phases detected in this section, based on the oldest ages for each area, are a coarse-grained first approximation to the spatio-chronological distribution that, as we will see next, correlates adequately with the groups derived from clustering.

Cluster analysis

The Silhouette Coefficient Analysis (SCA), as expected, provides the most conservative grouping of the calibrated age ranges, showing only two groups or major clusters. The first one includes ages from #1 to #52 from Table 1, coarsely ranging between ~ 500 and ~ 1300 CE. This time block roughly identifies the oldest occupations in the areas covered by blocks I and II, as outlined in the previous section.

The second SCA cluster includes all ages after ~ 1300 CE, coinciding with the beginning of the third block identified in Fig. 6. The resulting Average Silhouette Width is high (~ 0.65), demonstrating well-defined clusters (Fig. 7, left graph). This result is significant not only because it marks a crucial moment in the Guaraní expansion process around 1300 CE, which separates these two major clusters (to be analyzed in more detail later), but also because it supports the geo-chronological block analysis from the previous section, grouping the first two geo-chronological blocks within Cluster 1 and the last block within Cluster 2.

Due to its nature, the Silhouette Coefficient Analysis provides more synthetic results, which, although significantly reducing statistical noise, is less appealing in archaeological terms. Therefore, we analyzed the calibrated series (upper and lower age limits from Table 1) using Principal Component Analysis (PCA), which allows us to observe variances across two axes and potentially detect smaller clusters not identified by the SCA. In fact, the PCA further subdivides each of the two main clusters previously identified into two subgroups, resulting in four minor clusters depicted in Fig. 7 (right graph).

The first PCA cluster encompasses ages #1 to #4 from Table 1 corresponding to the earliest chronological ranges previously isolated in Sect. "The earliest sites and the initial colonization area", which seem to reflect the initial colonization process. Cluster 2 spans from age #5 to #52, coinciding with the upper boundary of the first major SCA cluster, around 1300 CE. Following the results along the two PCA axes, a third and fourth cluster can be identified between ages #53 to #268 (Cluster 3), and between #269 to #313 (Cluster 4) (Fig. 7, right graph). Cluster 3 begins with age #53 (Table 1),

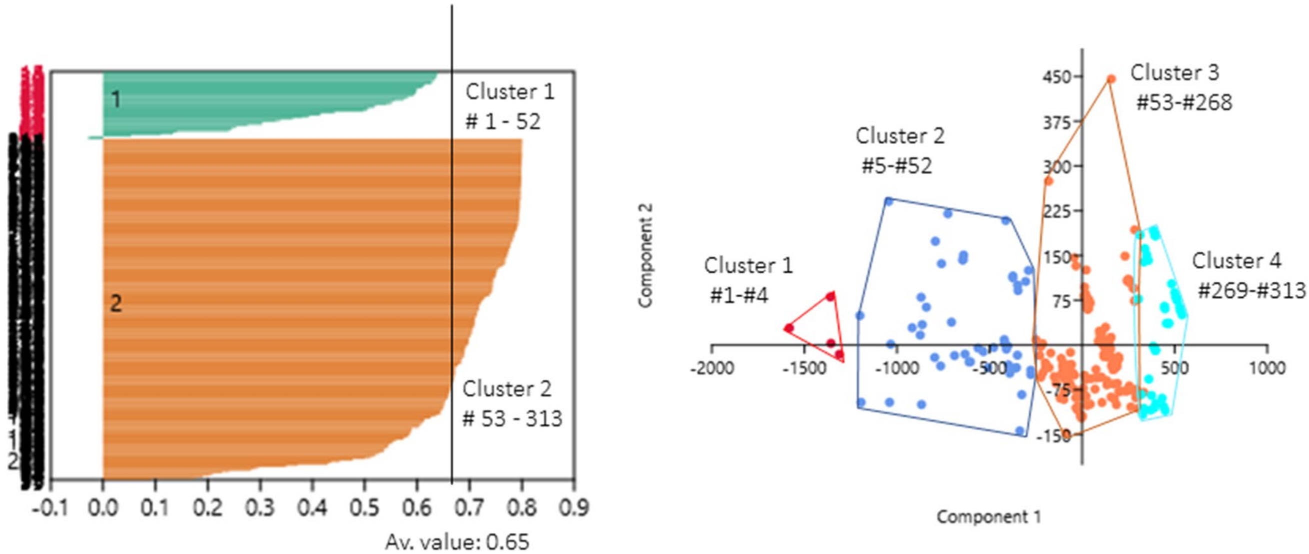

Fig. 7 Silhouette Coefficient Analysis (SCA) (left graph) and Principal Component Analysis (PCA) (right graph) based on the calibrated ranges of the ages from Table 1

which has an initial point near 1300 CE. The calibrated upper limit of this set of ages reaches ~ 1650 CE (up to age #268), making it reasonable to establish a boundary for this cluster around 1600 CE. Cluster 4 begins around 1600 CE, covering ages #269 to #313, which correspond to the most recent ages within the entire Guaraní dataset (Fig. 7, right graph).

Hierarchical Cluster Analysis (HCA) notably increases the number of groups (Fig. 8). Meanwhile the minor groupings are statistical artifacts with little interest for our analyses, those with a higher hierarchy largely respect in general terms the two previous analyses. In fact, the HCA identifies Cluster 1 (from #1 to #9), reflecting the initial colonization phase from approximately 500 to 800 CE. Meanwhile, Cluster 2 (a + b) represents a subsequent expansion phase from approximately 800 to 1300 CE. Cluster 3 begins at around age #53, spanning from 1300 CE to #252, roughly 1600 CE. Finally, Cluster 4 comprises samples ≥ #253, from approximately 1600 CE onward (Fig. 8). Despite the stratigraphic constraints and the wide dispersion of several radiocarbon and TL ages, the dendrogram's cophenetic correlation of 0.77 indicates a high level (≥ 0.8) of agreement, reflecting reasonable fidelity to the available data.

The results obtained in the previous analyses show that the Guaraní record has an internal chronological structure which can be divided into four main clusters, identified through both PCA and HCA, which in turn follow the outcomes derived from SCA and in agreement with the territorial expansion noted in the geo-chronological blocks of Fig. 6.

The summary of these results is as follows: Cluster 1 or **Phase I** is located in the upper Paraná basin (Fig. 9, left map), spanning from ~ 500 to ~ 800 CE representing the initial colonization stage (from the beginning of the step I, Fig. 6). Cluster 2 or **Phase II** extends from ~ 800 to ~ 1300 CE (Fig. 9, right map), reflecting a slight increase in the number of sites compared to the previous cluster and significant territorial expansion, as illustrated at the beginning of step II in Fig. 6, and the site dispersion in Fig. 9 (right map). During this phase, the Atlantic coast was reached around 1000 CE, and the middle section of the Uruguay River a few centuries later, towards the end of this phase. If this were the case, the Guaraní favored an expansion towards the east rather than the south at that latitude, probably because the Central Depression of Rio Grande do Sul, which ultimately reaches the Atlantic coast, was a wide tropical rainforest similar to that of the upper basin, while to the south, along the coasts of the middle and lower Uruguay River, this tropical forest formation disappears, giving way to a depleted subtropical riparian forest compared to the previous one.

The archaeological record of this phase does not indicate a saturation of the landscapes, but rather a strategy of discontinuous occupation of the space, likely involving a limited or moderate process of splitting major villages in each newly colonized territory. However, this new dispersion still does not reach the maximum expansion observed in the Cluster 3 or **Phase III**, occurring between ~ 1300 and 1600 CE, roughly corresponding to the third block in Fig. 6, with a site dispersion as depicted in Fig. 10 (left map). During this period, the Guaraní record demonstrates its widest territorial coverage, detected as far as the Paraná Delta and Río de la Plata ~ 1300 CE. This phase also reveals a significant increase in the number of inhabited sites, which appears to correspond to notable population growth, probably resulting in the saturation of space in different areas (Fig. 10 left map; Supplementary Fig. 1; see also Sect. "Discussion").

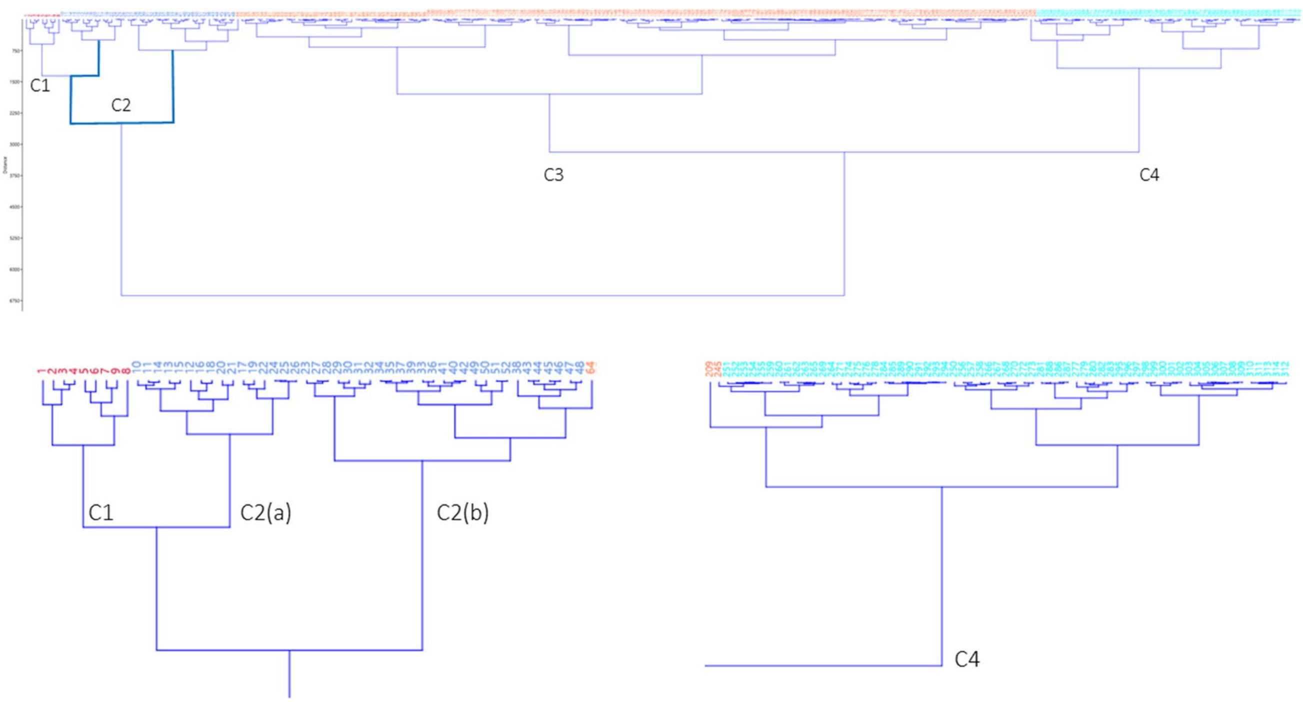

Fig. 8 Grouping via Hierarchical Cluster Analysis of the calibrated ranges from Table 1 (Euclidean similarity index; Ward´s algorithm; stratigraphic constrain based on calibrated ranges). The top section presents the overall grouping, while the bottom provides a detailed view of the extreme sections of the dendrogram. The marginal overlaps are basically due to some ages with wide ranges. Albino Mazzari radiocarbon age (#6 from Table 1) requires validation

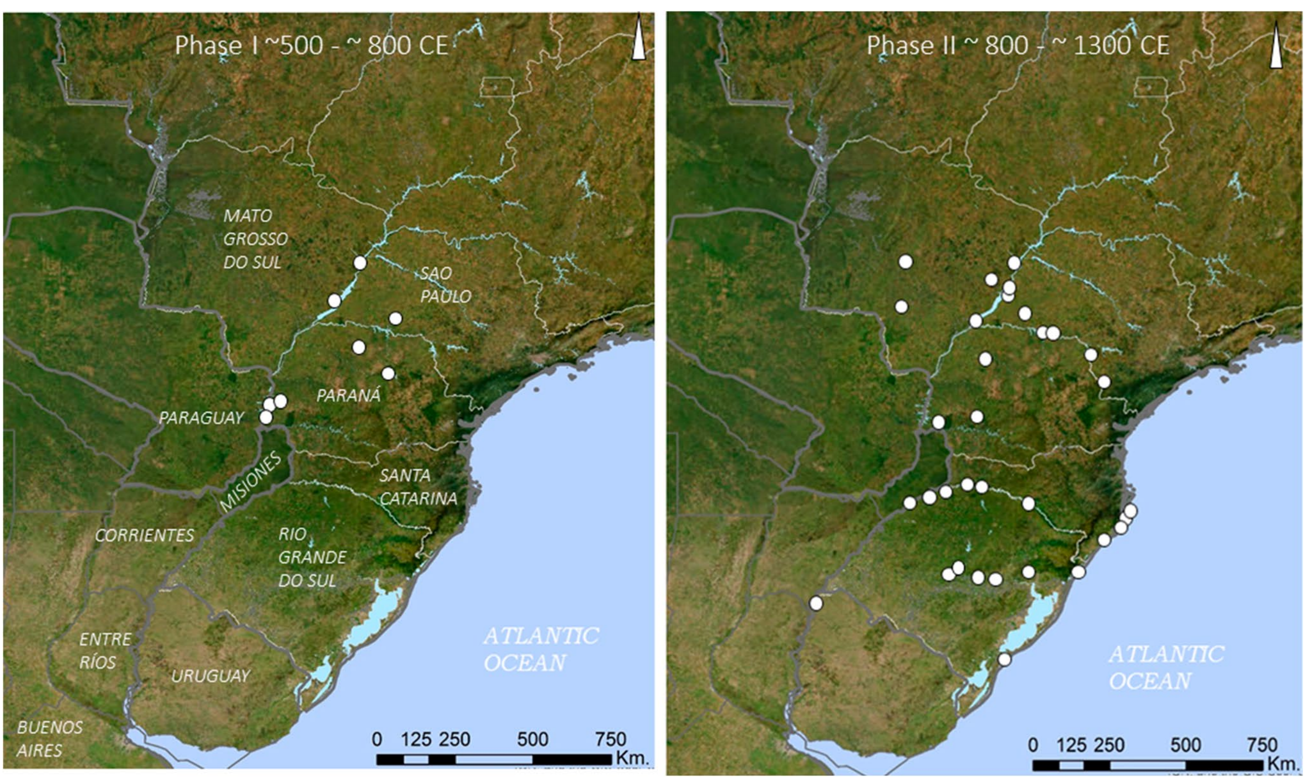

Fig. 9 Distribution of Guaraní dated sites included in Phase I (left) and Phase II (right). Both Albino Mazzari radiocarbon ages (#6 and #19 from Table 1) are included in Phase II (see text)

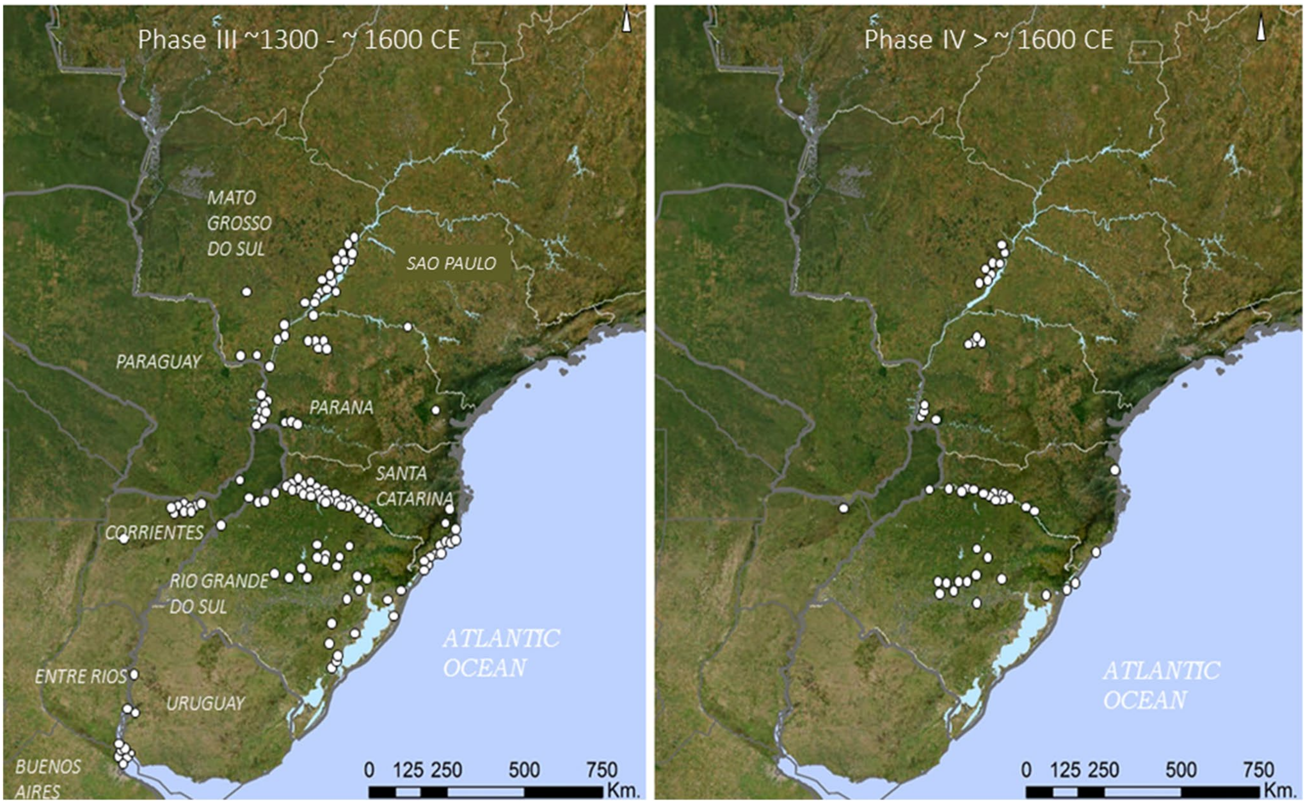

Fig. 10 Distribution of Guaraní dated sites included in Phase III (left) and Phase IV (right)

The results of the SPD (see below) suggest that this process was preceded by a slight rise occurring around 100 or 150 years earlier, starting ~ 1250 CE (Fig. 11).

Finally, Cluster 4 or **Phase IV** represents the most recent phase, corresponding to historical times and associated with a period of resilience during the early European expansion. The sites from this phase are concentrated in regions that remained outside European control during the early colonial period (e.g., the upper Uruguay River valley, the Upper Paraná, and parts of northern Rio Grande do Sul) (Fig. 9, right map). In contrast, Guaraní sites either disappear or significantly diminish in areas under European control, such as the Paraná Delta near Buenos Aires, which became a colonial administrative center around 1580 CE, or along the southern Atlantic coast of Brazil, which was colonized by European empires beginning in the sixteenth century. While it is possible that this distribution may be partially influenced by the intensity of archaeological investigations, this does not seem to be the case for areas like the Paraná Delta or parts of Rio Grande do Sul, including the Atlantic coast, where extensive surveys have been conducted. It is also important to highlight that the clustering analyses not only align with each other but also corroborate a straightforward visual inspection of the data (Figs. 9 – 11; Supplementary Fig. 1).

Previous distribution analyses do not consider the northern and eastern regions of Paraguay and the lowlands of Bolivia, where the Guaraní record is poorly known. Some early ages from this latter country obtained by Pärssinen (2005) require a better description of the dated contexts before being accepted. However, it is already perceived that the lowlands of Bolivia and the neighborhood Brazilian areas of southwest Amazonia can offer important clues to understand the overall Guaraní expansion process (see also Sect. "The dispersal of the Tupi-Guaraní").

Paleo demography

Various approaches have been used to estimate the demography of past populations, ranging from simple distributions of uncalibrated ages of sites to computational models, including multiple proxy data (Ames 1991; Contreras and Meadows 2014; Crema 2022; Crema and Bevan 2021a, b; Drennan et al. 2015; French et al. 2021; Marchetti et al. 2023; Rick 1987, among others). In most studies, the size and number of sites per time period are central to interpretive models of past demographic density. However, it is important to note that Guaraní sites cannot be detected through aerial imagery or satellite monitoring techniques, as they

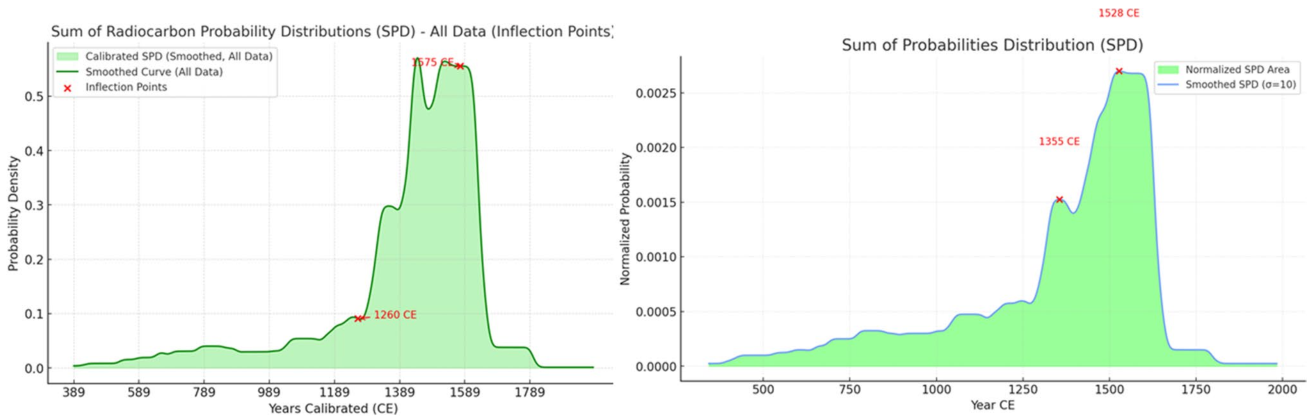

Fig. 11 Left: SPD of the radiocarbon dates from Table 1 with calibrated upper ranges below 1800 CE. Right: SPD of all radiocarbon dates included in Table 1 with calibrated upper ranges below 1800 CE, incorporating Bayesian averages for ages from the same site with overlapping chronological ranges. The scale is normalized. Both graphs were generated using Python with the libraries matplotlib (Hunter 2007) and scipy (Virtanen et al. 2020). The smoothed curve was generated using a Gaussian filter (σ = 10). The ages of the inflection points were calculated based on the second derivative

lack visible surface structures. This limitation means they can only be identified through field surveys.

Another crucial aspect to consider is that most studies on Guaraní sites do not report their size, making it impossible to evaluate whether there was a trend toward clustering or population dispersion over time, or whether the number of individuals per site changed. Additionally, the potential partial overlap of sites with different chronologies introduces distortions when interpreting site size in relation to demographic fluctuations.

While some studies have explored stylistic differences in specific Guaraní assemblages within certain regions, there is currently no comprehensive database that reliably correlates ceramic stylistic or typological variations with chronology. As a result, sites must be dated individually to establish their antiquity, limiting demographic pulse estimates to those sites with chronological determination based on TL or radiocarbon dating.

Regarding other proxy data in the archaeological literature, paleoclimatic fluctuations are also commonly used as sources of information to estimate paleodemographic parameters (e.g., Riede 2009; Kelly et al. 2013; Stiner and Kuhn 2006). However, the La Plata basin still lacks a detailed paleoclimatic record to evaluate Guaraní expansion, although this relationship has been explored in some specific areas (e.g., Iriarte et al. 2017; Loponte et al. 2024a, b).

Given these limitations, the most reliable and effective method currently available to analyze demographic changes related to Guaraní expansion relies on chronology and the spatial distribution of sites. To assess this, we generated Summed Probability Distribution (SPD) graphs that include all radiocarbon determinations from Guaraní sites with calibrated ranges up to 1800 CE. To prevent oversampling bias, we also created a second SPD graph that applies Bayesian averaging to dates originating from the same sites with overlapping calibrated ranges (Fig. 11). In both analyses, the results are consistent, showing that the Guaraní record between ~ 500 CE and ~ 1200 CE appears as a weak archaeological signal, with a gradual increase, followed by exponential growth starting from 1250–1300 CE, and a sharp decline after 1600 CE. These results suggest small founder populations in the various areas colonized throughout the basin and the Atlantic slope, with low demographic levels until ~1250 CE. This would be reflected in large, unpopulated intermediate areas between different Guaraní colonized territories. A significant change occurs after 1300 CE and continues until 1600 CE, marked by a notable increase in both the number of sites and the areas occupied, likely driven by a Guaraní demographic peak during this period.

Discussion

The antiquity of Guaraní colonization in the upper basin

Taking into account the results described above, the most solid evidence of the earliest Guaraní colonization emerges around the year 500 ± 100 CE in the upper La Plata Basin (~ 1500 cal BP). This antiquity is slightly more recent (up to 500 years) than what was postulated in other studies (e.g., Bonomo et al. 2015; Brochado 1984; Gregorio de Souza and Riris 2021; López Mazz and López Cabral 2020; Noelli 1999–2000; Noelli and Corrêa 2016; Scatamacchia 1990). The differences with previous models that analyzed the Guaraní expansion primarily stem from the exclusion of certain chronological determinations that do not correspond to Guaraní sites or archaeological layers, as well as dates that behave as extreme outliers or lack adequate analytical quality to be used as key dates, which compromise the reliability of the chronological framework. By following best practices in the management of chronological series observed in archaeological literature, these exclusions ensure a somewhat restricted but more robust analysis, allowing for the future incorporation of new dates. Furthermore, the results obtained align more closely with the chronology proposed by linguistic models, although significant challenges remain in reconciling both sources of information (see Sect. "The dispersal of the Tupi-Guaraní").

From the perspective of the archaeological record, at least three aspects still seriously limit our understanding of the initial phase of the expansion process. First, the uneven geographical distribution of the available chronological record excludes large areas, such as the Pantanal, the interior of Mato Grosso do Sul, Paraguay, Bolivia, and Misiones Province. Second, as with any probabilistic sampling, the current results are influenced by the available sample sizes. Consequently, the possibility of slightly earlier occupations in the basin cannot be entirely ruled out. Third, the existence of sites corresponding to an initial exploration phase—during which cognitive maps of the territories to be colonized were outlined (Kelly 2003)—cannot be dismissed. These early occupations, typically brief, are difficult to detect, as they often result in shallow sites with scattered materials or palimpsests mixed with later occupations, which should be properly identified.

The initial colonization area

In Sect. "Results", we emphasized that the earliest Guaraní dates (#1 to #4, Table 1) were detected around the tri-border region depicted in Fig. 5. If slightly more recent chronological ranges, such as up to #9 in Table 1 (excluding #6, whose range requires validation) are included, the average location remains consistent. This suggests that this area could represent the initial colonization sector along the upper Paraná River. Unfortunately, very little is known about the Guaraní archaeology of Paraguay and the interior of Mato Grosso do Sul, including the Pantanal, where numerous undated Guaraní sites have been identified (e.g., Peixoto 1995), which could significantly enhance our understanding of the expansion process.

Another relevant aspect emerging from previous results is that the earliest Guaraní sites are arranged in a dispersed pattern (Fig. 5), with their northern dispersion boundary located near the Tieté and Paranapanema rivers, a region previously identified as the northern limit of the dispersion of these assemblages (e.g., Brochado 1984; Kashimoto and Martins 2009; Corrêa 2014).

Changes in the chronology of Guaraní expansion

The results from Sect. "Results" revise the age and location of the beginning of Guaraní colonization in the basin, better aligning with the linguistic data (Sect. "The dispersal of the Tupi-Guaraní"). They also redefine the timeline of Guaraní colonization in several areas. Among the most significant changes is the reassessment of the northwest of Corrientes province, previously thought to have been occupied by the Guaraní population around 200 CE (Bonomo et al. 2015). This assumption was based on a single radiocarbon determination that stands out as an isolated extreme outlier, as the remaining 22 dates for that region are approximately 1,000 years later (see Supplementary Text). Consequently, the hypothesis of Guaraní colonization of this area around 200 CE cannot be sustained without new evidence. Current reliable data indicate that this area was colonized during Phase III, beginning ~ 1300 CE (Sect. "Results"). Given its proximity to Misiones province, slightly earlier occupations toward the end of Phase II cannot be ruled out and warrant future investigation.

The third major revision concerns the chronology of Guaraní occupation in Rio Grande do Sul. Previous models (Bonomo et al. 2015; Noelli 1999–2000) proposed an early occupation of the Central Depression (~ 274 CE) based on a questionable determination from the RS-MJ-88 site (see Supplementary Text 1). In contrast, the most reliable evidence comes from the Capané 3 site, dated to ~ 800 CE, which aligns with the upper range (~ 700 CE) of the Albino Mazzari site (Table 1, Sect. "Results"). Furthermore, this range of ~ 700 to 800 CE matches the adjusted timeline for the neighboring upper Uruguay River region (Sect. "The earliest sites and the initial colonization area"), suggesting a more or less simultaneous occupation of both areas at the beginning of Phase II.

The fourth significant revision involves the antiquity of the Guaraní occupation in the upper valley of the Uruguay River, previously proposed to have occurred after 1000 CE, later than the Central Depression of Rio Grande do Sul (e.g., Bonomo et al. 2015: map 6). However, current evidence shows Guaraní occupations in the upper Uruguay River region beginning between 773 and 888 CE (age #12, Table 1), indicating an approximately contemporaneous antiquity with the Guaraní occupation of the Central Depression of Rio Grande do Sul.

Phases of the expansion and retraction

The small number of sites identified in Cluster C1 (Fig. 8) or Phase I distributed according to Fig. 9 (left map) does not indicate a sudden and massive population appearance in the initial colonization area of the basin, but rather seems to correspond to founder populations with low demographic density, as evidenced by the SPD up until ~1250 CE, a range that includes subsequent Phase II. Although this later phase shows a slight increase in the number of sites and territorial coverage, the Guaraní archaeological signal remains very weak. Therefore, it is unlikely that Phases I and II represent spatial saturation through successive village division and gradual occupation of adjacent areas, as suggested by some traditional models of Guaraní expansion. Instead, these phases seem to reflect a discontinuous occupation of the landscapes with low population density. Additionally, these areas were already inhabited by pre-existing populations that coexisted with the early phases of Guaraní expansion, hindering or obstructing continuous occupation of the space. To understand the expected archaeological record of a phase of space saturation, we can briefly describe the ethnographic panorama derived from chronicles about other Tupí groups during the 16th and early seventeenth centuries in the northeastern Atlantic Forest. These populations, with a social and economic system equivalent to that of the Guaraní and within a similar environment, occupied territories with villages separated by 8 to 20 km, housing between 560 and 1600 people. Within each territory, villages and small settlements could relocate between 1.6 and 6.0 km due to soil exhaustion or forest encroachment on cultivated plots. These internal movements occurred on average every four years, facilitating the opening of new cultivation areas (Barreto and Drummond 2017). Abandoned areas within each territory continued to be used for various purposes, including former villages, before eventually being reoccupied. These practices generate an almost continuous record in the landscape, which is not observed during Phases I and II (between ~ 500 and ~ 1300 CE) (Fig. 9, top maps) but becomes evident during Phase III (Fig. 10, left map).

Taphonomic and other biases do not seem to significantly affect the record during Phase I and II, as just a few centuries later, during Phase III, the archaeological evidence is distributed continuously, at least in some intensively studied sectors (Upper Paraná, Upper Uruguay, Taquarí basin and some areas of the Atlantic coast) (Fig. 10, left map). Furthermore, during Phases I and II, these territories were inhabited by preexisting populations, which likely influenced a more or less discontinuous occupation of space. These non-Guaraní populations also had a partially or completely overlapping niche with the Guaraní, as they were also forager-horticulturalists, making them absolute competitors. This does not rule out the possibility that in some areas, Guaraní populations may have created initially saturated spaces during Phases I and II.

Another ethnographic example can provide a conceptual framework to approach the scheme that may have developed during Phases I and II of the Guaraní colonization of the basin. The Tapirapé is a Tupian-speaking group that in the seventeenth century moved from the lower Tocantins and Xingu rivers to the Araguaia River, between the border of the states of Pará and Mato Grosso, in a movement of displacement hundreds of kilometers. Although the reason for this migration is not clear, these groups had already cognitively constructed the map of the destination patch, knowing what type of environment and what other groups were in the destination area (Baldus 1970). The new villages in the upper Araguaia were dispersed in the landscape, with distances of up to 10 days' walks between them, passing through well-established territories of groups of the Macro-Jê language family that conditioned the location of the Tapirapé villages. After some time, the Tapirapé villages split due to population growth and soil fertility decline. These new smaller settlements or even large villages could relocate to nearby or very distant areas, depending on multiple environmental and social factors (Baldus 1970; Wagley 1988). This scheme, clearly, does not represent a slow saturation of space through radial scheme to the large villages and may reflect, to some extent, the process being observed during Phases I and II of Guaraní expansion in the basin.

Another important aspect to highlight from the results obtained here concerns the year 1000 CE, which some previous models consider a pivotal moment marked by a significant increase in the number of sites and territorial coverage. However, as we have observed, this is not the case. The period around 1000 CE corresponds to a mid-phase of Phase II, characterized by a modest rise in the number of sites and moderate territorial expansion. In contrast, the most significant territorial expansion and peak demographic growth began around 1250–1300 CE, culminating between 1400 and 1600 CE (Sect. "Results").

Finally, Phase IV represents the end of this long sequence, marked by an abrupt geographical retraction, indicative of a resilience phase. One of the greatest challenges in analyzing the chronology of this period is that most modern calibration ranges of radiocarbon ages are excessively wide, as they fall within successive plateaus and reversals in the calibration curve (SHCal20) between ca. 1460–1640 CE and ca. > 1660 CE. This issue causes the calibrated ranges for this period—critical for understanding social and political changes—to be overly extended.

Another challenge in analyzing this later period arises from radiocarbon ages that may reflect activities of early Western settlers in previously abandoned Guaraní villages. These calibrated ranges extend from the 17th or 18th centuries to the contemporary era. Consequently, the TL dating method presents a significant opportunity to study this period, as it bypasses the issues associated with radiocarbon calibration curves and directly determinate the age of the vessels. On the other hand, the resilience phase outlined earlier and depicted in Fig. 10 (right map) is undoubtedly more complex. As we have seen, one of the major movements of Guaraní population appears to have been a retreat into territories beyond European control. However, both the historical and material records indicate a new Guaraní diaspora extending beyond the dispersal shown in Fig. 10 (right map) of this study. A significant portion of the Guaraní population was relocated to Jesuit Missions, where some cultural traits persisted, albeit altered by the colonial process (e.g., Brochado 1984; Ocampo 2020, among others).

A smaller fraction of the Guaraní population appears to have dispersed into areas previously unoccupied by them, or into marginal regions at the onset of European expansion, leading to a complex process of ethnogenesis with other human groups. This makes archaeological identification particularly challenging. These movements may partially explain the presence of isolated Guaraní burials from historical periods found at non-Guaraní sites, where their presence is minimal and outside the typical lowland forest and Atlantic coast regions. One such example is the Isla Larga site (Cerrito San Miguel) in Uruguay (Cabrera et al. 2000, 2014). Additionally, another segment of the Guaraní population integrated into the rural and urban centers of the emerging colonial society, where certain cultural practices, such as pottery production, persisted, albeit to varying degrees and under the influence of European colonization. This is evidenced by colonial sites where unmistakably Guaraní ceramics have been identified in contexts dating up to the eighteenth century (Zorzi and Agnolin 2013).

Figure 12 summarizes the distribution of ^{14}C ages for the complete Guaraní sequence across the La Plata basin and the Atlantic slope, alongside the proposed phases.

Migration rates

There are some previous approximations regarding Guaraní expansion rates. Rogge (2005) based on data from Rio Grande do Sul, estimated a rate between 0.8 and 1 km/year akin to that observed in non-canoe societies of the European Neolithic (Rogge 2005: 201). At the Upper Uruguay River, a similar rate was calculated by Gregorio de Souza et al. (2016). However, this last result requires revision as for this calculation, the Beta code 118,377 age 900 ± 50 ^{14}C BP was used as if it corresponded to the Guaraní site SC-U-71 (Sect. "Quality and assignation of radiocarbon and TL ages").

If we consider the data presented in Table 1 of this study, we can estimate the expansion rate from the upper basin, taking the tri-state border of Mato Grosso do Sul, Paraná, and the Republic of Paraguay (see Sect. "The earliest sites and the initial colonization area") as a starting point around 500 CE, and the earliest age from the Paraná Delta, obtained

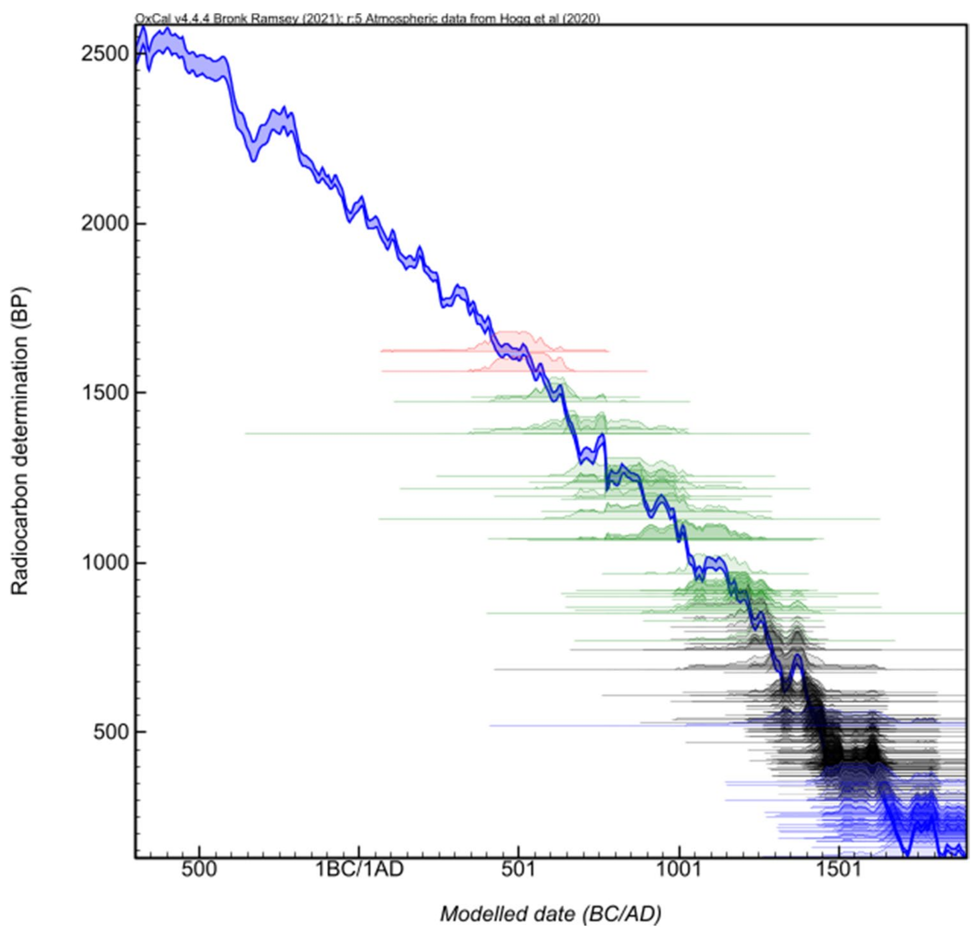

Fig. 12 Distribution of radiocarbon ages according to the main clusters identified in the HCA: Phase I is shown in red, Phase II in green, Phase III in black, and Phase IV in blue

from the Arroyo Fredes site, with a midpoint of 1326 CE (age #63 from Table 1). The spatiotemporal difference spans 1370 km of distance (according to the route represented in Supplementary Fig. 2-A) covered over 826 calendar years, resulting in an expansion rate of ~ 1.7 km per year. If we consider the upper calibrated range of the Arroyo Fredes age (1423 CE), the expansion rate is ~ 1.5 km per year. A more cautious estimate can be made by considering this same upper range of Arroyo Fredes and the oldest midpoint from Table 1 of 330 CE, as we have already mentioned, should be taken cautiously (see Sect. "The earliest sites and the initial colonization area"). The expansion rate calculated in this way yields an average of ~ 1.3 km per year.

The second rate can be estimated between the same point in the upper basin and the headwaters of the Uruguay River. Here, the earliest site and closest to its sources corresponds to Antônio Dilson Castro (age #12, Table 1), dated to 1240 ± 15 ^{14}C BP, with a calibrated range of 773—888 CE, and 831 CE as midpoint (Table 1). The two most likely paths to connect both points are depicted in Supplementary Fig. 2-B. The distances of each one is ~ 860 and ~ 750 km respectively. Taking an average of 800 km of distance covered over a span of 331 years, results in a rate of 2.4 km/year. If we consider the midpoint of age #1 from Table 1 (330 CE) with the necessary precautions, the migration rate is substantially reduced to 1.6 km/year.

The third rate we estimate here is from the same initial point in the upper basin to the Atlantic coast. The access route is more complex to determine. The distribution of the record and the ages suggest that the most probable route was descending south the Paraná River, reaching and descending south again by the Uruguay River, and through its left tributaries entering the Central Depression of the state of Rio Grande do Sul, reaching the Atlantic coast (Supplementary Fig. 2-C), where the Guaraní record appears *ca.* 1000 CE (see Sect. "Cluster analysis"). The distance thus measured is ~ 1400 km, resulting in a rate of 2.8 km/year, which is reduced to 2.1 km/year if age #1 is considered.

The overall results range from ~ 1.3 to ~ 2.8 km/year. This variability, in addition to inherent methodological issues and the fact that not all areas of Guaraní expansion are interconnected by waterways, is to be expected when populations expand across diverse landscapes with varying degrees of resistance to movement, including specific ecological differences, topographic features, pre-existing populations, and other factors (Bocquet-Appel et al. 2012). It should be noted, however, that the rates obtained for areas connected by major rivers such as the Paraná and Uruguay are lower than those reported for other migrations that relied on navigation devices (e.g., Fort 2022; Wagley 1988). Improvements to the database will enable the confrontation and refinement of these dispersion rates which are a coarse-grained approximation.

Final remarks

The Guaraní expansion from Amazonia to southeastern South America stands out as one of the most remarkable migrations documented for a canoe-based society in the Americas. This expansion likely involved a combination of long-distance migrations led by pioneer populations, leaving uncolonized areas, along with medium to short-distance movements. This diverse pattern of colonization carries significant implications for Guaraní archaeology, particularly concerning metapopulation dynamics, cultural evolution, innovation, and learning systems within Guaraní society, which extend the boundaries of research in exciting new directions.

In this study, we have proposed different ways of grouping the data that we believe reflect some of the underlying structures of the Guaraní expansion. However, there are several alternative approaches, each offering different perspectives that will help enrich the discussion. We have also highlighted the need to improve various aspects of the databases and methodological issues related to Guaraní archaeology. This includes increasing sample sizes, especially from underrepresented regions, validating dating methodologies, and obtaining accurate paleoclimatic data directly relevant to the research. Addressing these and other issues will ensure the continuous improvement and expansion of the database. Although this study has improved the database, it still contains data that require ongoing and consistent scrutiny. Another crucial aspect is fostering international cooperation, as demonstrated by this study. The effective advancement of Guaraní archaeology requires collaboration among researchers working in key active research areas, consistently generating new field and laboratory data based on shared standards. Finally, this study also aims to stimulate discussion, identify the strengths and weaknesses of our knowledge on the analyzed topics, while addressing the numerous gaps for a better understanding of Guaraní archaeology, which is undergoing an undeniable process of theoretical and methodological growth, as well as an increase in the quantity of ongoing research.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12520-024-02158-3.

Acknowledgements We thanks to Drs. Emília Kashimoto, Sonia Hatsue Tatumi, Klaus Hilbert, Gislene Monticelli, Angelo Corrêa and Rodrigo Lavina for information, discussions and ideas, and to the three reviewers who improved the text with their suggestions and observations. This research was possible due to the grants of the National Council for Scientific and Technological Development (CNPq), concerning to the Grants 312543/2022-0 and 305353/2021-7, and several grants and academic institutions from Brazil, Argentina and Uruguay.

Author Contribution Daniel Loponte: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Visualization; Roles/Writing—original draft; and Writing—review & editing Mirian Carbonera: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Visualization; Roles/Writing—original draft; and Writing—review & editing Fernanda Schneider: Data curation, investigation, validation; visualization, review & editing Andrés Gascue: Data curation, investigation, validation; visualization, review & editing Rafael Guedes Milheira: Data curation, investigation, validation; visualization, review & editing Marcos César Pereira Santos: Data curation, investigation, validation; visualization, review & editing Juliano Bitencourt Campos: Data curation, investigation, validation; visualization, review & editing Jedson Cerezer: Data curation, investigation, validation; visualization, review & editing Antoine Lourdeau: Data curation, investigation, validation; visualization, review & editing Alejandro Acosta: Data curation, investigation, validation; visualization, review & editing Noelia Bortolotto: Data curation, investigation, validation; visualization, review & editing Jairo Rogge: Data curation, investigation, Neli Teresinha Machado: Data curation, investigation, validation; visualization, review & editing Sheila Ali: Data curation, investigation, validation; visualization, review & editing Maricel Pérez: Data curation, investigation, validation; visualization, review & editing Dione da Rocha Bandeira: Data curation, investigation, validation; visualization, review & editing Isabella Muller: Data curation, investigation, validation; visualization, review & editing Jaqueline Borger: Data curation, investigation, validation; visualization, review & editing.

Funding There was no funding.

Data Availability No datasets were generated or analysed during the current study.

Declarations

Competing Interests The authors declare no competing interests.

References

Acosta A, Carbonera M, Loponte D (2019) Archaeological hunting patterns of Amazonian horticulturists: The Guaraní example. Int J Osteoarchaeol 29(6):999–1012. https://doi.org/10.1002/oa.2813

Admiraal M, Colonese A, Milheira R, Bandeira DR, Demathe A, Pereira dos Santos M, Fossile T, Talbot H, Bondetti M, Lucquin A, Montalvo Cabrera J, Prates L, Serna A, Craig OE (2023) Chemical analysis of pottery reveals the transition from a maritime to a plant-based economy in pre-colonial coastal Brazil. Sci Rep 13(1):16771. https://doi.org/10.1038/s41598-023-42662-5

Aitken MJ (1985) Thermoluminescence dating. Academic Press, London

Aitken MJ (1998) An introduction to optical dating. University Press, Oxford

Almeida FO (2013) A Tradição Polícroma no Alto Rio Madeira. Dissertation, Universidade de São Paulo

Alves A (2012) Arqueologia Guaraní em uma Aldeia no litoral sudoeste da Laguna dos Patos, Sítio PS-03 − Totó. Dissertation, Universidade de São Paulo

Ambrosetti JB (1895) Los cementerios prehistóricos del Alto Paraná (Misiones). Boletín Del Instituto Geográfico Argentino 16:227–263

Ames KM (1991) The archaeology of the Longue Durée: Temporal and spatial scale in the evolution of social complexity in southern northwest coast. Antiquity 65:935–945

Attenbrow V, Hiscock P (2015) Ages and demography: are radiometric ages a robust proxy for long-term prehistoric demographic change? Archaeol Ocean 50:30–36

Baldus H (1970) Tapirapé: Tribo Tupí no Brasil Central. Companhia Editora Nacional, São Paulo

Barreto CG, Drummond JA (2017) Cambios antropogénicos en los paisajes del bosque atlántico brasileño en el periodo precolombino. Revista De Historia Iberoamericana 10(1):10–33. https://doi.org/10.3232/RHI.2017.V10.N1.01

Batalha-Filho H, Fjeldsa J, Fabre P-H, Miyaki CY (2013) Connections between the Atlantic and the Amazonian forest avifaunas represent distinct historical events. J Ornithol 154(1):41–50. https://doi.org/10.1007/s10336-012-0866-7

Bespalez E (2010) Levantamento arqueológico na aldeia Lalima, Miranda/MS: uma contribuição ao estudo da trajetória histórica da ocupação indígena regional. Revista De Arqueologia 23(2):118–146

Beta Report (1998) Report of radiocarbon dating analyses for Dr. Klaus Hilbert

Beta Report (1999) Report of radiocarbon dating analyses for Dr. Klaus Hilbert

Bocquet-Appel JP et al (2012) Understanding the rates of expansion of the farming system in Europe. J Archaeol Sci 39:531–546

Bonomo M, Angrizani RC, Apolinaire E, Noelli FS (2015) A model for the Guaraní expansion in the La Plata Basin and litoral zone of southern Brazil. Quatern Int 356:54–73. https://doi.org/10.1016/j.quaint.2014.10.050

Bracco R, Fregeiro M, Panarello H, Odino R, Souto B (2000) Dieta, modos de producción de alimentos y complejidad. Comparación de la dieta de los “constructores de cerritos” del Este de la República Oriental del Uruguay con otras regiones del mismo territorio. In: Durán A, Bracco R (eds) Arqueología de las Tierras Bajas. MEC, Montevideo, pp 227–248

Brochado JP (1969) Pesquisas arqueológicas nos vales do Ijuí e do Jacuí. Publicaçoes, Avulsas Do Museu Paranaense Emilio Goeldi 13:31–62

Brochado JP (1971) Extensão das pesquisas arqueológicas nos vales do Jacuí e Ibi-cuí-Mirim, Rio Grande do Sul. Publicações Avulsas Do Museu Paranaense Emílio Goeldi 15:11–36

Brochado JP (1973) Migraciones que difundieron la tradición alfarera Tupí-Guaraní. Relaciones De La Sociedad Argentina De Antropología 7:7–39

Brochado JP (1984) An Ecological Model f the Spread of Pottery and Agriculture Into the Eastern South America. Dissertation, University of Illinois at Urbana

Brochado JP, Monticelli G (1994) Regras práticas na reconstrução gráfica das vasilhas de cerâmica Guaraní a partir dos fragmentos. Estudos Ibero-Americanos 20(2):107–118

Brochado J, Monticelli G, Neumann E (1990) Analogia etnográfica na reconstrução das vasilhas Guaraní arqueológicas. Veritas 35(140):727–743

Bronk Ramsey C (2021) OxCal v.4.4.4 [software]. https://c14.arch.ox.ac.uk/oxcal/OxCal.html. Accessed 20 Feb 2024

Cabrera L, Durán A, Femenías J, Marozzi O (2000) Investigaciones arqueológicas en el sitio CG14E01 (“Isla Larga”) Sierra de San Miguel (Rocha, Uruguay). In: Duran A, Bracco R (eds) Arqueología de las Tierras Bajas. MEC, Montevideo, pp 183–194

Cabrera L, Lusiardo A, Figueiro GM (2014) Señales de muerte violenta en un enterramiento en montículo en el este de Uruguay. In: López Mazz JM and Berón M (eds) Indicadores arqueológicos de violencia, guerra y conflicto en Sudamérica. UdelaR, Montevideo, pp 37–54

Caldarelli S (2008) Relatório parcial do Projeto Arqueologia Preventiva na Expansão do Sistema de Transmissão Acre-Rondônia,

subprojeto 1: Salvamento Arqueológico na Linha do Transmissão 230 kV Ji-Paraná - Pimenta Bueno - Vilhena – Rondônia
Caldarelli S (2010) Arqueologia preventiva na UHE Foz do Chapecó, SC/RS. Relatório final. Scientia Consultoria Científica, Florianópolis
Campos JB, Perin EB (2023) Relatório de Pesquisa do Programa de Gestão ao Patrimônio Arqueológico do Condomínio Blue Lagoon - município de Balneário Rincão/SC. Arqueosul. Unpublished report, Criciúma
Campos JB, Deblasis P, Perin EB, Schneider F, Ferrasso S, Araújo AL, Silva RE, Fonseca RG, Silveira PV, Dagostim SAP (2023) Muita comida, pouca gente: perspectivas acerca dos sítios rasos do litoral norte do Rio Grande do Sul. Boletim Do Museu Paraense Emílio Goeldi Ciências Humanas 18:e20220077
Carbonera M (2014) A ocupação pré-colonial do alto Rio Uruguai, SC: contatos culturais na Volta do Uvá. Dissertation, Universidade de São Paulo
Carbonera M, Loponte D (2018) Contribução ao estudo tipológico e estilístico da ceramica do sítio Corpus da provincia de Misiones, Argentina. XI Encontro da Sociedade de Arqueologia Brasileira Núcleo Regional Sul, pp 22–23
Carbonera M, Lourdeau A, Silva SFSM, Hatté C, Fontugne M, Kuczkovski F, Santos MCP, Herberts AL, Ghizzo I, Onghero A (2018) Estudo de uma deposição funerária pré-colonial Guarani do Alto Rio Uruguai, SC: escavação e obtenção dos dados dos perfis funerário e biológico. Bol Mu Para Emílio Goeldi 13(3):625–644. https://doi.org/10.1590/1981.81222018000300008
Carbonera M, Schneider F, Machado N, Loponte D (2022) Estudos isotópicos da dieta Guaraní e a cadeia trófica associada à bacia do rio Taquari, Rio Grande do Sul. Revista De Antropología Del Museo De Entre Ríos 7(1):30–44
Carbonera M et al (2024) Dentro e fora da urna: deposições funerárias da unidade arqueológica Guaraní a partir do sítio Uruguai 1, na Foz do Chapecó (RS). Bol Mus Para Emílio Goeldi 19(2):e20230056
Carle M (2002) Investigação arqueológica em Rio Grande: uma proposta da ocupação Guaraní pré-história no Rio Grande do Sul. Dissertation, Pontifícia Universidade Católica do Rio Grande do Sul
Cerezer JF (2017) Tecnologia e simbolismo na expansão Guaraní no Sul do Brasil. Dissertation, Universidade de Trás-os-Montes-Alta Douro
César JV (1966) Enterros em urnas dos Tupi-Guaraní. Rev Antropol 14:53–72
Chmyz I (1967) Dados parciais sobre a arqueologia do vale do rio Paranapanema. Publicações Avulsas Do Museu Paranaense Emílio Goeldi 6:59–78
Chmyz I (1969a) Dados parciais sobre a arqueologia do vale do rio Ivaí. Publicações Avulsas Do Museu Paranaense Emílio Goeldi 10:95–118
Chmyz I (1969b) Pesquisas arqueológicas no Alto e Médio Iguaçu. Publicações Avulsas Do Museu Paranaense Emílio Goeldi 13:103–132
Chmyz I (1983) Sétimo Relatório do Projeto Arqueológico Itaipu. Itaipu/Iphan, Curitiba
Chmyz I, Chmyz JC (1986) Datações radiométricas em áreas de salvamento arqueológico do Estado do Paraná. Revista Do Cepa 5:69–77
Cigliano ME (1968) Investigaciones arqueológicas en el río Uruguay medio y la costa NE de la provincia de Buenos Aires. Pesquisas, Antropologia 18:5–9
Contreras DA, Meadows J (2014) Summed radiocarbon calibrations as a population proxy: A critical evaluation using a realistic simulation approach. J Archaeol Sci 52:591–608
Corrêa AA (2009) Tetama nas Matas Mineiras: sítios Tupi na microrregião de Juiz de Fora-MG. Dissertation, Universidade de São Paulo
Corrêa AA (2014) Pindorama de mboîa e îakaré: continuidade e mudança na trajetória das populações Tupi. Dissertation, Universidade de Sao Paulo
Costa Angrizani R (2012) Variabilidad, Movilidad y Paisaje: una propuesta interpretativa para los vestigios de los asentamientos precoloniales en el noroeste del Rio Grande do Sul (Brasil). Dissertation, Universidad Nacional de La Plata
Crema ER (2022) Statistical Inference of Prehistoric Demography from Frequency Distributions of Radiocarbon Ages: A Review and a Guide for the Perplexed. J Archaeol Method Theory 29:1387–1418. https://doi.org/10.1007/s10816-022-09559-5
Crema ER, Bevan A (2021a) Inference from large sets of radiocarbon ages: software and methods. Radiocarbon 63(1):23–39
Crema E, Bevan A (2021b) Inference from large sets of radiocarbon ages: Software and methods. Radiocarbon 63:23–39
Cristante MAP (2018) Arqueologia Das Práticas Mortuárias De Grupos Tupinambá E Guaraní. CLIO Arqueológica 33:184–245
da Bandeira DR (2004) Ceramistas Pré-coloniais da Baía da Babitonga - Arqueologia e Etnicidade. Dissertation, Universidade Estadual de Campinas
De Masi MA (2001) Pescadores Coletores da Costa Sul do Brasil. Pesquisas Antropologia 57:1–136
De Masi MAN (2012) Relatório Projeto de Salvamento Arqueológico UHE Foz do Chapecó (Reservatório). Florianópolis
Domiks J (2001) Adornos corporais, ferramentas e material fito-faunístico dos sítios arqueológicos da UHE Machadinho. Divulgação Museu Ciência e Tecnologia 6:137–151
Drennan RD, Berry AC, Peterson CE (2015) Regional settlement Demography in archaeology. Eliot Werner Publications, New York
Faccio N (1992) Estudo do Sítio Arqueológico Alvim no Contexto do Projeto Para-napanema. Dissertation, Universidade de São Paulo
Faccio N (1998) Arqueologia dos cenarios das ocupaçoes horticultoras de Capivara, baixo Parapanema. Dissertation. Universidade de Sao Paulo
Farías M (2005). El Guaraní arqueológico meridional, entre el axioma y la heterodoxia. Dissertation, Pontifícia Universidade Católica do Rio Grande do Sul
Fausto (1992) Fragmentos de história e cultura Tupinambá. Da etnologia como instrumento crítico de conhecimento etno-histórico. In: Cunha MC da (ed) História dos Índios no Brasil. Companhia das Letras, São Paulo, pp 381–396
Ferraz Gerardi F, Tresoldi T, Coelho Aragon C, Reichert S, de Souza JG, Noelli FS (2023) Lexical phylogenetics of the Tupi-Guaraní family: Language, archaeology, and the problem of chronology. PLoS ONE 18(6):e0272226. https://doi.org/10.1371/journal.pone.0272226
Fiegenbaum J (2009) Um assentamento TupiGuaraní no vale do Taquari. Dissertation, Universidade do Vale do Rio dos Sinos
Fort J (2022) Dispersal distances and cultural effects in the spread of the Neolithic along the northern Mediterranean coast. Archaeol Anthropol Sci 14:153
French JC, Riris P, Fernandéz-López de Pablo J, Lozano S, Silva F (2021) A manifesto for palaeodemography in the twenty-first century. Phil Trans R Soc B 376:20190707
Gamble C, Davies W, Pettitt P, Hazelwood L, Richards M (2005) The archaeological and genetic foundations of the European population during the Late Glacial: implications for ‘agricultural thinking.’ Camb Archaeol J 15(2):193–223
Gascue G, Bortolotto N, Loponte D, Acosta A, Borges C, Fleitas M, Fodrini A (2019) Contextos geomorfológicos y tecnoeconómicos del registro arqueológico del bajo río Uruguay (margen

izquierda). Resultados Preliminares De Nuevas Prospecciones Arqueología 25(3):87–117

Gaulier P (2001) Ocupação pré-história Guaraní no município de Porto Alegre, RS: considerações preliminares e primeira datação do sítio arqueológico RS-LC-71: Ilha Francisco Manuel. Revista de Arqueologia 14/15:57–73

Gregorio de Souza J, Riris F (2021) Delayed demographic transition following the adoption of cultivated plants in the eastern La Plata Basin and Atlantic coast. South America J Archaeol Sci 125:105293. https://doi.org/10.1016/j.jas.2020.105293

Gregorio de Souza J, Corteletti R, Robinson M, Iriarte J (2016) The genesis of monuments: Resisting outsiders in the contested landscapes of southern Brazil. J Anthropol Archaeol 41:196–212

Gregorio de Souza J, Alcaina Mateos J, Madella M (2020) Archaeological expansions in tropical South America during the late Holocene: Assessing the role of demic diffusion. PLoS ONE 15(4):e0232367

Harmon MJ, VanPool TL, Leonard RD, VanPool CS, Salter LA (2006) Reconstructing the Flow of Information across Time and Space: A Phylogenetic Analysis of Ceramic Traditions from Prehispanic Western and Northern Mexico and the American Southwest. In: Lipo CP, O'Brien M, Collard M, Shennan SJ (eds) Mapping our Ancestors. Phylogenetic Approaches in Anthropology and Prehistory. Aldine Transaction, New Brunswick, pp 209–230

Hilbert K (1999) Arqueologia Guaraní na região de Guaíba e RS. Resumos da X Reunião Científica da Sociedade de Arqueologia Brasileira. Recife, p 133

Hiscock P, Attenbrow V (2016) Ages and demography? The need for caution in using radiometric ages as a robust proxy for prehistoric population change. Archaeol Ocean 51(3):218–219

Hogg AG, Heaton TJ, Hua Q, Palmer JG et al (2020) SHCal20 Southern Hemisphere calibration, 0–55000 years cal BP. Radiocarbon 62:759–778

Hunter JD (2007) Matplotlib: A 2D graphics environment. Comput Sci Eng 9(3):90–95. https://doi.org/10.1109/MCSE.2007.55

Iriarte J, Smith RJ, Gregorio de Souza J, Mayle FE, Whitney BS et al (2017) Out of Amazonia: Late-Holocene climate change and the Tupi-Guaraní trans-continental expansion. The Holocene 27(7):967–975

Kashimoto E, Martins G (2008) A problemática arqueológica da Tradição cerâmica Tupi-Guaraní no Mato Grosso do Sul. In: Prous A, Lima TA (eds) Os ceramistas tupi-Guaraní. Sigma, Belo Horizonte, pp 149–178

Kashimoto E, Martins G (2009) Arqueologia e Paleoambiente do rio Paraná em Mato Grosso do Sul. Life Editora. Campo Grande

Kelly RL (2003) Colonization of new land by Hunter-Gatherers: expectations and implications base on ethnographic data. In: Rockman M, Steele J (eds) The Colonization of Unfamiliar Landscapes. Routledge, The Archaeology of Adaptation, pp 44–58

Kelly RL, Surovell TA, Shuman BN, Smith GMA (2013) continuous climatic impact on Holocene human population in the Rocky Mountains. Proc Natl Acad Sci USA 110:443–447

Kennett DJ, Culleton BJ, Dexter J, Mensing SA, Thomas DH (2014) High-Precision AMS 14 C chronology for Gatecliff Shelter, Nevada. J Archaeol Sci 52:621–632. https://doi.org/10.1016/j.jas.2014.06.008

Kreutz MR (2008) O contexto ambiental e as primeiras ocupações humanas do Vale do Taquari-RS. Dissertation, Centro Universitário Univates

Kreutz MR (2015) Movimentações de populações Guaraní, século XIII ao XIX - Bacia Hidrográfica do Rio Taquari, Rio Grande do Sul. Dissertation, Universidade do Vale do Taquari-Univates

Kusiak J, Rychter M, Stasiak-Cyran M (2011) Attempts at thermoluminescence dating of fired materials from the przeworsk culture settlements. Geochronometria 38(4):359–368. https://doi.org/10.2478/s13386-011-0026-5

La Salvia F, Brochado J (1989) Cerâmica Guaraní. Posenato Arte and Cultura. Porto Alegre

Laming A, Emperaire J (1959) A jazida José Vieira. Um sítio Guaraní e pré-cerâmica no interior do Paraná. Centro de Ensino e Pesquisa Arqueológica: Arqueologia 1. Univerisdade do Paraná: Curitiba

Laming Emperaire A (1968) Missions archéologiques françaises au Chili Austral et au Brésil Meridional. Datations de quelques sites par le radiocarbone. J Da Société des Américanistes 57:77–99. https://doi.org/10.3406/jas.1968.2038

Lavina R (org) (1999) Projeto de Salvamento Arqueológico da ZPE-Imbituba, SC. Relatório Final. Unesc, Criciúma

Lavina, R (org) (2000) Relatório Final. Projeto de salvamento arqueológico da rodovia interpraias (Trecho Morro dos Conventos – Lagoa dos Esteves). Unesc, Criciúma

Ledo RMD, Colli GR (2017) The historical connections between the Amazon and the Atlantic Forest revisited. J Biogeogr 44:1–13. https://doi.org/10.1111/jbi.13049

Liu Y, Hayes DN, Nobel AB, Marron JS (2008) Statistical significance of clustering for high-dimension, low-sample size data. J Am Stat Assoc 103:1281–1293. https://doi.org/10.1198/016214508000000454

Long A (1965) Smithsonian Institution radiocarbon measurements II. Radiocarbon 7:245–256

Long A, Mielke J (1967) Smithsonian Institution radiocarbon measurements IV. Radiocarbon 6:368–381

López Mazz J, López Cabral RM (2020) The presence of Guaraní groups in the current Uruguayan territory. J Anthropol Archaeol 59:101193

Loponte D (2020) La agricultura prehispánica del nordeste de Argentina analizada a través de los isótopos estables. Anuario De Arqueología 12:25–64

Loponte D, Acosta A (2003) Nuevas perspectivas para la arqueología "Guaraní" en el humedal del Paraná inferior y Río de la Plata. Cuadernos Del Instituto Nacional De Antropología y Pensamiento Latinoamericano 20:179–197

Loponte D, Acosta A (2013) La construcción de la unidad arqueológica Guaraní en el extremo meridional de su distribución geográfica Cuadernos del Instituto Nacional de Antropología y Pensamiento Latinoamericano. Series Especiales 1(4):193–235

Loponte D, Carbonera M (2021) From the Atlantic coast to the lowland forests: Stable isotope analysis of the diet of forager–horticulturists in southern Brazil. Int J Osteoarchaeol 31(6):1237–1246

Loponte D, Acosta A, Capparelli I, Pérez M (2011) La arqueología guaraní en el extremo meridional de la cuenca del Plata. In: Loponte DM, Acosta A (eds) Arqueología Tupiguaraní. Instituto Nacional de Antropología y Pensamiento Latinoamericano, Buenos Aires, pp 111–154

Loponte D, Ottalagano F, Bortolotto N, Gascue A, Viglioco D, Boretto R (2016) Avances en la arqueología del bajo río Uruguay: el sitio La Yeguada, Departamento de Río Negro (Uruguay). Revista Tessituras 4(1):8–52

Loponte A, Acosta A, Gascue A, Pfrengle S, Schuenemann V et al (2023) The southernmost pre-Columbian dogs in the Americas. Morphometry, phenotype, chronology, diet and genetics. Environ Archaeol 28(6):443–474

Loponte D, Carbonera M, Radaeski J (2024a) The Guaraní expansion in the Upper Uruguay River. Chronology, colonization strategies, social impacts and environmental changes. J Archaeol Sci Rep 60:104826

Loponte D, Acosta A, Gascue A, Carbonera M, Benazzi S, Bortolini E, Quarta G, Calcagnile L, Marciani G, Bortolotto N (2024b) Radiocarbon dating and Bayesian modeling of pre-Columbian occupations in the Paraná Delta, Argentina. 4th International Conference on Radiocarbon in the Environment Conference. RE-IV Conference, Lecce, p 120

Loponte D, Carbonera M, Schneider F, Machado M, Bertoncello A, Telles Szczygel M, Acosta A, Mazza B, Alí S, Capparelli I (2025) At the Southern limit: the arenal central site and the guaraní occupation of the Paraná Delta (Argentina). Front Environ Archaeol X:1–46. In press
Lourdeau A, Carbonera M, Pereira Santos MC, Hoeltz S et al (2016) Pré-história na foz do rio Chapecó. Cadernos Do CEOM 29:220–242
Machado AJ (2008) Avançar, adaptar e permanecer: a Tradição TupiGuaraní no médi rio das Antas. Dissertation, Universidade do Vale do Rio dos Sinos, São Leopoldo
Machado AF, Ritter CD, Miranda CL, Bredin YK et al (2021) Potential mammalian species for investigating the past connections between Amazonia and the Atlantic Forest. PLoS ONE 16(4):e0250016. https://doi.org/10.1371/journal.pone.0250016
Marchetti N, Bortolini E, Menghi Sartorio JC et al (2023) Long-Term Urban and Population Trends in the Southern Mesopotamian Floodplains. J Archaeol Res. https://doi.org/10.1007/s10814-024-09197-3
Martínez-Grau H, Morell-Rovira B, Antolín F (2021) Radiocarbon ages associated to neolithic contexts (ca. 5900 – 2000 cal BC) from the northwestern Mediterranean arch to the high Rhine area. J Open Archaeol Data 9(1):1. https://doi.org/10.5334/joad.72
Martins GR, Kashimoto EM, Tatumi SH (1999) Datações arqueológicas em Mato Grosso do Sul. Revista Do Museu De Arqueologia e Etnologia 9:73–93
Mazza B, Acosta A, Loponte D (2016) Nuevos datos para las inhumaciones en urnas de sitios arqueológicos Guaraníes del extremo meridional de la Cuenca del Plata. Revista Chilena De Antropología 34:81–96
Mielke J, Long A (1969) Smithsonian Institution radiocarbon measurements V. Radiocarbon 11(1):163–182
Milheira RG (2008) Território e Estratégia de Assentamento Guaraní na Planície Sudoeste da Laguna dos Patos e Serra do Sudeste/RS. Dissertation, Universidade de São Paulo
Milheira RG (2010) Arqueologia Guaraní no litoral sul-catarinense: história e território. Dissertation, Universidade de São Paulo
Milheira R (2014) Arqueologia Guaraní na laguna dos Patos e serra do Sudeste, 1ª. Editora da UFPel, Pelotas
Milheira RG, De Blasis P (2011) O território Guaraní no litoral sul catarinense: ocupação e abandono no limiar do período colonial. Revista De Arqueologia Americana 29:147–182
Milheira RG, Loponte D, Acosta A, Esponda C, Ulguim Y (2016) The First Record of a Pre-Columbian Domestic Dog (Canis lupus Familiaris) in Brazil. Int J Osteoarchaeol 27(3):488–494
Miller ET (1967) Pesquisas arqueológicas efetuadas no nordeste do Rio Grande do Sul. Publicações Avulsas Do Museu Paranaense Emílio Goeldi 6:15–38
Miller ET (1969) Pesquisas arqueológicas efetuadas no noroeste do Rio Grande do Sul. Publicaçoes Avulsas Do Museu Paranaense Emílo Goeldi 10:33–54
Miller ET (2009) A Cultura Cerâmica do Tronco Tupí no alto Ji-Paraná, Rondônia, Brasil: Algumas Reflexões Teóricas, Hipotéticas e Conclusivas. Revista Brasileira De Linguística Antropológica 1(1):35–136
Mujica JI (1995a) Primeras aproximaciones sobre el uso del espacio abierto en una aldea guaraní prehispanica, in Actas y Memorias del XI Congreso Nacional de Arqueología Argentina, San Rafael, pp 123–141
Mujica JI (1995b) De Corrientes Argentina. Informe de dos sitios arqueológicos guaraní en la província. In: XX Encuentro de Geohistoria Regional (Gobernador Virasoro, Argentina). pp 119–127
Mujica JI (1995c) Un sitio guaraní en el centro de la provincia de Corrientes -Llamarada- Santa Rosa. Depto. de Concepcion, in XX Encuentro de Geohistoria Regional Gobernador Virasoro, Argentina), 99:135–148
Müller LM, Souza SHFM de (2011) Enterramentos Guaraní: problematização e novos achados. In Carbonera M, Schmitz PI (eds) Antes do Oeste de Santa Catarina: arqueologia dos povos indígenas. Argos, Chapecó, pp 167–218
Noelli FS (2004) La distribución geográfica de Las evidencias arqueológicas guaraní. Revista De Indias LXIV 230:17–34
Noelli FS, Corrêa AA (2016) Arqueologia regional e a construção das paisagens Guaraní na margem esquerda do rio Paraná, Estado do Paraná, Brasil. Cadernos Do Ceom 45:87–112. https://doi.org/10.22562/2016.45.04
Noelli FS (1993) Sem tekoha não há tekó: em busca de um modelo etnoarqueológico da subsistência e da aldeia Guaraní aplicado a uma área de domínio do delta do Jacuí – RS. 1993. Dissertation, Pontifícia Universidade Católica do Rio Grande do Sul
Noelli FS (1999–2000) A ocupação humana na Região Sul do Brasil: arqueologia, debates e perspectivas (1872–2000). Revista USP. Antes de Cabral: Arqueologia Brasileira II 44:218–269
Novasco RV, Mello ADB, Cerezer JF et al (2021) Apontamentos sobre a ocupação Guaraní no litoral sul de Santa Catarina: o caso do sítio arqueológico baixo rio d'una 1. Pesquisas, Antropologia 76:129–142
O'Brien M, Lyman RL (2002) The epistemological nature of archaeological units. Anthropol Theory 2:37–56
O'Brien M, Lee Lyman R, Mesoudi A, VanPool T (2010) Cultural traits as units of analysis. Phil Trans R Soc B 365:3797–3806
Ocampo A (2020) Arqueología Histórica en contextos de trasformación urbana. El caso de Concepción de la Sierra (Misiones, Argentina). Entre la materialidad arqueológica y la patrimonialización de un pueblo misionero. Dissertation, Universidad Nacional de Misiones
O'Hagan Z, Chousou-Polydouri N, Michael L (2019) Phylogenetic classification supports a Northeastern Amazonian Proto-Tupí-Guaraní homeland. LIAMES: Línguas, Indígenas Americana 19(1–29):e019018
Pärssinen M (2005) Quando começou, realmente, a expansão Guaraní em direção às Serras Andinas Orientais? Revista De Arqueologia 18:51–66
Peixoto JL (1995) A Ocupação TupiGuaraní na Borda Oeste do Pantanal Sul-matogrossense: maciço do Urucum. Dissertation, Pontifícia Universidade Católica do Rio Grande do Sul
Pereira Santos MC (2018) Geoarqueologia da area da Volta Grande do Alto Rio Uruguai, Sul do Brasil: morfoestratigrafia, geocronología e sequencia arqueológico da foz do rio Chapecó. Dissertation, Universitá degli Studi di Ferrara
Pereira Santos MC, Pavei DD, Campos JB (2016) Arqueologia Entre Rios: do Urussanga ao Mampituba. Paleoambiente, cultura material e ocupação humana na paisagem litorânea do extremo sul catarinense entre 3500–200 anos AP. Cadernos Do CEOM 29:64–86
Pereira Santos MC, Carbonera M, Rosina P, Schuster AJ et al (2021) Holocene settlement, stratigraphy and chronology at the site of Uruguai 1, sector 1, Foz do Chapecó archaeological area, South Brazil. J Archaeol Sci Rep 39:103113. https://doi.org/10.1016/j.jasrep.2021.103113
Piazza W (1969) Notícia arqueológica do vale do Uruguai. Publicações Avulsas Do Museu Paranaense Emílio Goeldi 10:55–70
Prous A, Lima TA (2008) Os ceramistas Tupi-Guaraní. Sigma, Belo Horizonte
Ribeiro PAM (1968) Os sítios arqueologicos do vale do rio Caí. Pesquisas Antropologia 18:153–169
Ribeiro PAM (1974) Primeiras datações pelo método C14 para o vale do Caí, Rio Grande do Sul. Revista Do CEPA 1:16–22
Ribeiro PAM (1991) Arqueologia do vale do rio Pardo, Rio Grande do Sul Brasil. Revista Do CEPA 18(21):1–184
Ribeiro PAM, Ribeiro CT, Silveira I, Klamt SC (1986) Levantamentos arqueológicos nos altos vales dos rios Camaquã e Irapúa, RS, Brasil. Revista Do CEPA 15:41–70

Rick JW (1987) Ages as data: An examination of the Peruvian radiocarbon record. Am Antiq 52:55–73

Riede F (2009) Climate and demography in early prehistory: using calibrated 14C dates as population proxies. Hum Biol 81:309–337

Riede F (2011) Steps towards operationalizing an evolutionary archaeological definition of culture. In: Roberts BW, Vander Linden M (eds) Investigating archaeological cultures: material culture, variability, and transmission. Springer, New York, pp 245–270

Riris P, Silva F (2021) Resolution and the detection of cultural dispersals: development and application of spatiotemporal methods in Lowland South America. Humanit Soc Sci Commun 8:36. https://doi.org/10.1057/s41599-021-00717-w

Rodríguez JA (1997) Investigaciones arqueológicas en Yacyretá (Corrientes- Argentina). Jornadas De Antropología De La Cuenca Del Plata 3:41e47

Rodríguez JA (2009) La ocupacion (poblamiento) del norte de Corrientes (Argentina) por fase de la Tradicion Tupiguaraní. In: Meggers B (ed) Arqueologia interpretativa. O método quantitativo para o estabelecimento de sequências cerâmicas: estudos de casos. Unitins, Porto Nacional, pp 49–62

Rogge JH (2005) Fenômenos de fronteira: um estudo das situações de contato entre portadores das tradições cerâmicas pré-históricas no Rio Grande do Sul. Pesquisas, Antropologia 62:9–119

Rohr JA (1969) Pesquisas arqueológicas do município sul-catarinense de Jaguaruna. Pesquisas Antropologia 22:1–37

Rosa AO (2006) A importância dos mariscos na subsistência de antigos grupos indígenas do litoral central do Rio Grande do Sul. Pesquisas, Antropologia 63:259–288

Rousseeuw PJ (1987) Silhouettes: A Graphical Aid to the Interpretation and Validation of Cluster Analysis. Comput Appl Math 20:53–65

Scatamacchia MCM (1990) A tradição policrômica no leste da América do Sul evidenciada pela ocupação Guaraní e Tupinambá: fontes arqueologicas e etnohistóricas. Dissertation, Universidade de São Paulo

Schmidl U (1948) Viaje a la Regiones del Plata. Editorial Peuser. Buenos Aires

Schmitz PI (n.d.) Lista de datas do Pronapa. Ms

Schmitz PI, Brochado JP (1972) Dados para uma sequência cultural do Estado de Rio Grande do Sul, Brasil. Gabinete de Arqueologia, 2. Universidade Federal do Rio Grande do Sul, Porto Alegre

Schmitz PI, Sandrin C (2009) O Sítio Lagoa dos Índios e o Povoamento Guaraní da Planície Costeira do Rio Grande do Sul. Documentos-Instituto Anchietano De Pesquisas 11:89–134

Schmitz PI, Rogge JH, Nunes J, Rathke RH (2019) O Povoamento Guaraní do Vale do Rio dos Sinos. Pesquisas, Antropologia 74:3–195

Schneider F (2014) Interpretação do espaço Guaraní: um estudo de caso no sul da Bacia Hidrográfica do Rio Forqueta, Rio Grande do Sul, Brasil. Dissertation, Centro Universitário Univates

Schneider F (2019) Poder, transformação e permanência: a dinâmica de ocupação Guaraní na Bacia do Taquari-Antas, Rio Grande do Sul, Brasil. Dissertation, Universidade do Vale do Taquari

Schneider F, Wolf S, Kreutz MR, Machado NTG (2017) Tempo e Espaço Guaraní: um estudo acerca da ocupação, cronologia e dinâmica de movimentação pré-colonial na Bacia do Rio Taquari/Antas, Rio Grande do Sul, Brasil. Boletim Do Museu Paraense Emílio Goeldi Ciências Humanas 12:31–56

Schwengber VL, Claudino DC, Cerezer JF (2017) Programa de resgate arqueológico nas áreas de extração de areia - localidade de jaboticabeira e morro bonito. Município de jaguaruna. Tubarão. Final Report

Sempé MC, Caggiano MA (1995) Las culturas agroalfareras del Alto río Uruguay (Misiones). Argentina. Revista Do Museu De Arqueologia e Etnologia 5:27–38

Smith M (2016) The use of summed-probability plots of radiocarbon data in archaeology. Archaeol Ocean 51(3):214–215

Soares ALR (1997) Os Guaraní. Organização Social e Arqueologia. Edipucrs, Porto Alegre

Soares ALR (2004) Contribuição à Arqueologia Guaraní: Estudo do Sítio Röpke. Dissertation, Universidade de São Paulo

Stiner MC, Kuhn SL (2006) Changes in the ‘connectedness’ and resilience of paleolithic societies in mediterranean ecosystems. Hum Ecol 34:693–712

Stuckenrath R, Mielke J (1970) Smithsonian Institution radiocarbon measurements VI. Radiocarbon 12(1):193–204

Stuckenrath R, Mielke J (1972) Smithsonian Institution radiocarbon measurements VII. Radiocarbon 14(2):401–412

Stuckenrath R, Mielke J (1973) Smithsonian Institution radiocarbon measurements. Radiocarbon 15(2):388–424

Tehrani J, Riede F (2008) Toward archaeology of pedagogy: learning, teaching and the faithful replication of complex cultural skills. World Archaeol 40(3):316–331

Virtanen P, Gommers R, Oliphant TE, Haberland M, Reddy T et al (2020) SciPy 1.0: Fundamental algorithms for scientific computing in Python. Nat Methods 17(3):261–272. https://doi.org/10.1038/s41592-019-0686-2

Wagley C (1988) Lágrimas de boas vindas: os índios Tapirapé do Brasil Central. Editora da Universidade de São Paulo, São Paulo

Wiessner P (1983) Style and social information in Kalahari San Projectil points. Am Antiq 2(48):253–276

Williams AN (2012) The use of summed radiocarbon probability distributions in archaeology: a review of methods. J Archaeol Sci 39(3):578–589

Wolf S (2012) Paisagens e Sistemas de Assentamento: um estudo sobre a ocupação humana pré-colonial na Bacia Hidrográfica do Rio Forqueta/RS. Dissertation, Universidade do Vale do Taquari

Zimpel NCA (2009) Na direção das periferias extremas da Amazônia: arqueología na bacia do rio Ji-Paraná, Rondônia. Dissertation, Universidade de São Paulo

Zimpel NCA (2018) A Fase Bacabal e seus Correlatos Arqueológicos na Amazônia. Dissertation, Universidade de São Paulo

Zorzi F, Agnolin A (2013) Análisis e reflexiones en torno a un conjunto cerámico colonial en la ciudad de Buenos Aires. Cuadernos Del Instituto Nacional De Antropología y Pensamiento Latinoamericano - Series Especiales 1(3):132–144

Authors and Affiliations

Daniel Loponte[1] · Mirian Carbonera[2] · Fernanda Schneider[1] · Andrés Gascue[3] · Rafael Guedes Milheira[4] · Marcos César Pereira Santos[5] · Juliano Bitencourt Campos[6] · Jedson Cerezer[7] · Antoine Lourdeau[8] · Alejandro Acosta[1] · Noelia Bortolotto[3] · Jairo Rogge[9] · Neli Teresinha Machado[10] · Sheila Ali[11] · Maricel Pérez[11] · Dione da Rocha Bandeira[12] · Isabella Muller[13] · Jaqueline Borger[14]

✉ Daniel Loponte
dashtown@gmail.com

Mirian Carbonera
mirianc@unochapeco.edu.br

Fernanda Schneider
fernandaschneider@universo.univates.br

Andrés Gascue
andresgascue@gmail.com

Rafael Guedes Milheira
milheirarafael@gmail.com

Marcos César Pereira Santos
marcoscesar.arqueologia@gmail.com

Juliano Bitencourt Campos
jbi@unesc.net

Jedson Cerezer
jfcpicci@gmail.com

Antoine Lourdeau
antoine.lourdeau@mnhn.fr

Alejandro Acosta
acostalejandroalberto@gmail.com

Jairo Rogge
rogge@unisinos.br

Neli Teresinha Machado
ngalarce@univates.br

Sheila Ali
sheilagriselali@gmail.com

Maricel Pérez
maricelperez@gmail.com

Dione da Rocha Bandeira
dione.rbandeira@gmail.com

Isabella Muller
isabeladsmuller@gmail.com

Jaqueline Borger
jaqueline.borger@unochapeco.edu.br

1 Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Instituto Nacional de Antropología y Pensamiento Latinoamericano (INALP), 3 de Febrero 1374 (C1426BJN) , Buenos Aires, Argentina

2 Centro de Memória Do Oeste de Santa Catarina and Programa de Pós-Graduação Em Ciências Ambientais da Universidade Comunitária da Região de Chapecó (Unochapecó). Researcher at CNPq, Chapecó, Brazil

3 Universidad de La República (Uruguay)-Centro Universitario Regional del Este -Departamento de Sistemas Agrarios y Paisajes Culturales, Intersección Rutas 9 y 15, Rocha, Punta del Este, Uruguay

4 Bacharelado Em Arqueologia E Programa de Pós-Graduação Em Antropologia da Universidade Federal de Pelotas. Coordenador Do Laboratório de Ensino E Pesquisa Em Antropologia E Arqueologia (LEPAARQ/UFPel). Pesquisador Do CNPq, Pelotas, Brazil

5 Programa de Pós-Graduação Em Antropologia da Universidade Federal de Pelotas (UFPel), Pelotas, Brazil

6 Programa de Pós-Graduação em Ciências Ambientais da Universidade do Extremo Sul Catarinense (UNESC), Criciúma, Brazil, and Instituto Terra E Memória, Centro de Geociências de Coimbra (ITM/CGEO) Researcher at CNPq, Coimbra, Portugal

7 Espaço Arqueologia, Tubarão, Brazil

8 Muséum National d’Histoire Naturelle, France, UMR 7194, Équipe PréTropz, Paris, France

9 Universidade Do Vale Do Rio Dos Sinos (Unisinos), São Leopoldo, Brazil

10 Coordenadora Do Laboratório de Arqueologia - Museu de Ciências E Docente Do Programa de Pós-Graduação Em Ambiente e Desenvolvimento da Universidade Do Vale Do Taquari (Univates), Lajeado, Brazil

11 Instituto Nacional de Antropología y Pensamiento Latinoamericano (INAPL), 3 de febrero 1378 (C1426BJN), Buenos Aires, Argentina

12 Programa de Pós-Graduação Em Patrimônio Cultural E Sociedade da Univille, Joinville, Brazil

13 Instituto Do Patrimônio Histórico E Artístico Nacional/SR Santa Catarina, Santa Catarina, Brazil

14 Universidade Comunitária da Região de Chapecó (Unochapecó), Chapecó, Brazil