Springer Earth System Sciences

Germán Mariano Gasparini
Jorge Rabassa
Cecilia Deschamps
Eduardo Pedro Tonni *Editors*

Marine Isotope Stage 3 in Southern South America, 60 ka B.P.–30 ka B.P.

Springer

Springer Earth System Sciences

Editors
Germán Mariano Gasparini
División Paleontología Vertebrados, Museo de La Plata
Facultad de Ciencias Naturales y Museo, Universidad Nacional de La Plata
La Plata, Buenos Aires
Argentina

Jorge Rabassa
Laboratorio de Geomorfología y Cuaternario
CADIC-CONICET, Universidad Nacional de Tierra del Fuego
Ushuaia, Tierra del Fuego
Argentina

Cecilia Deschamps
División Paleontología Vertebrados, Museo de La Plata
Facultad de Ciencias Naturales y Museo, Universidad Nacional de La Plata
La Plata, Buenos Aires
Argentina

Eduardo Pedro Tonni
División Paleontología Vertebrados, Museo de La Plata
Facultad de Ciencias Naturales y Museo, Universidad Nacional de La Plata
La Plata, Buenos Aires
Argentina

ISSN 2197-9596 ISSN 2197-960X (electronic)
Springer Earth System Sciences
ISBN 978-3-319-39998-0 ISBN 978-3-319-40000-6 (eBook)
DOI 10.1007/978-3-319-40000-6

Library of Congress Control Number: 2016943439

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG Switzerland

Contents

Marine Isotope Stage 3 (MIS 3) and Continental Beds from Northern Uruguay (Sopas Formation): Paleontology, Chronology, and Climate

Martín Ubilla, Andrea Corona, Andrés Rinderknecht, Daniel Perea and Mariano Verde

Abstract The Sopas Formation is a late Pleistocene continental unit that includes trace fossils, woods, fresh-water mollusks, and vertebrates with mammals being the predominant taxa. Likely, relationships with the Last Interglacial Stage or with the Last Interstadial were proposed. The paleontological content of the Sopas Formation is updated, and the climatic and environmental signals provided by the fossil content are evaluated. Radiocarbon AMS dates ranging from 33,560 ± 700 year B.P. (cal 36,089 − 39,426 year) to 39,900 ± 1,100 (cal 42,025 − 45,389 year) and TL/OSL ages from 27,400 ± 3,300 to 71,400 ± 11,000 year (being the 45–28 ka time interval better represented), support a relationship with Marine Isotopic Stage 3 (MIS 3) in most outcrops. In the fossil assemblage are taxa that indicate open habitats, savannahs, and woodlands including gallery forests and perennial rivers; living representatives of taxa related to benign climatic conditions (mostly tropical to temperate climates), some taxa that suggest arid to semiarid environments, migrants, and seasonality indicators. A replacement versus mixed faunal models is discussed in the light of available evidence.

M. Ubilla (✉) · A. Corona · A. Rinderknecht · D. Perea · M. Verde
Facultad de Ciencias, Universidad de la República (UDELAR), Montevideo, Uruguay
e-mail: martinubilla@gmail.com

A. Corona
e-mail: acorona@fcien.edu.uy

A. Rinderknecht
e-mail: apaleorinder@yahoo.com

D. Perea
e-mail: pereadnl@gmail.com

M. Verde
e-mail: icnologia@gmail.com

A. Rinderknecht
Museo Nacional de Historia Natural, Montevideo, Uruguay

G.M. Gasparini et al. (eds.), *Marine Isotope Stage 3 in Southern South America, 60 ka B.P.–30 ka B.P.*, Springer Earth System Sciences,
DOI 10.1007/978-3-319-40000-6_11

Keywords Marine isotope stage 3 (MIS 3) • Uruguay • Late Pleistocene • Sopas Formation

Abbreviations

AA	NSF-Arizona AMS Laboratory, USA
GX	Geochron Laboratories, USA
OSL	Optically stimulated luminescence
LP	Latyr, Laboratorio de Tritio y Radiocarbono, La Plata
LVD	Laboratório dataçao (LOE e TL), Sao Paulo
UIC	Luminescence Dating Research Laboratory, Department of Earth and Environmental Sciences, University of Illinois, Chicago
URU	Laboratorio de ^{14}C, Facultad de Química, Montevideo
NISP	Total number of identified specimens

1 Introduction

The Sopas Formation is a late Pleistocene continental unit that includes trace fossils, woods, fresh-water mollusks, and vertebrates with mammals being the predominant taxon (Ubilla 2004; Ubilla et al. 2004). According to biostratigraphy and numerical dating, this unit has been correlated with the Lujanian Stage/Age of the Buenos Aires province in Argentina (Late Pleistocene/Early Holocene, sensu Cione and Tonni 1999; Ubilla et al. 2004). Considering the numerical ages, the climatic and the environmental information provided by the fossil content, likely relationships with the Last Interglacial Stage or with the Last Interstadial were proposed (Ubilla and Perea 1999; Ubilla et al. 2004, 2009; Iriondo and Kröhling 2008). It seems that the faunal assemblage is older than those belonging to the Guerrero Member of the Luján Formation (Buenos Aires province, Argentina), which is in general related to the Last Glacial Maximum (Tonni et al. 1999). The Sopas Formation could be correlated with the "Secuencia deposicional Luján Verde Inferior" and in part with the "Secuencia deposicional Luján Rojo (Toledo 2011). The Touro Passo Formation in southwestern Brazil was correlated with the Sopas Formation (Bombín 1975) and yields some ages and taxa shared with this unit (Ribeiro and Scherer 2009; Kerber et al. 2011).

Currently, we have learned more about of the Interstadial Marine Isotopic Stage 3 (MIS 3) of the Last Glacial Stage (Van Meerbeeck et al. 2009; Tonni et al. 2010, 2011; Buiron et al. 2012; Rabassa and Ponce 2013; Long and Stoy 2013). This encompasses a period between ca. 60–25 ka, which is characterized by millennial climatic changes. These changes include sudden warming phases (the Dansgaard-Oeschger events) in addition to colder phases (the Heinrich events) in the northern hemisphere (Van Meerbeeck et al. 2009, 2011) and to a lesser extent in the southern hemisphere (Buiron et al. 2012; Paisani et al. 2014). The impact of these climatic processes in southern continental biota and how they are reflected in the fossil record is far from being understood.

The aims of this paper are: (a) to update the paleontological content of the northern late Pleistocene beds of Uruguay (the Sopas Formation), (b) to perform an appraisal of the climatic and environmental signals provided by the fossil content, and (c) to discuss their relationships with the MIS 3.

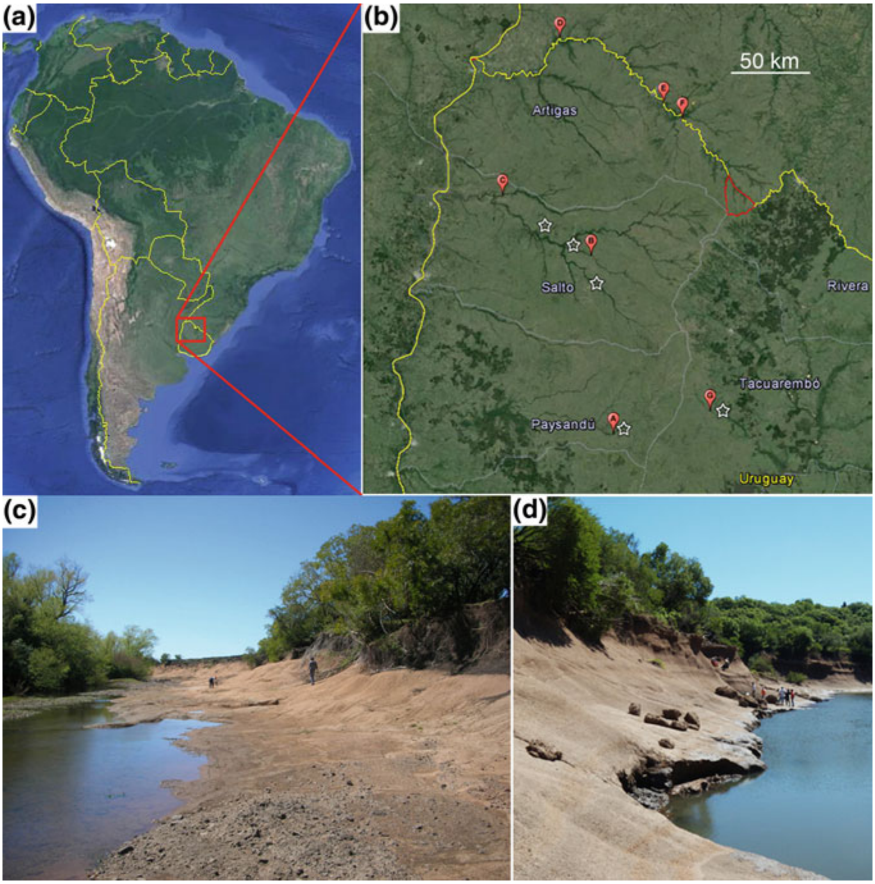

Fig. 1 **a**, **b** Geographic location of selected studied outcrops of the Sopas Formation in northern Uruguay (**b**: *a* Río Queguay, *b* Arroyo Sopas, *c* Río Arapey Chico, Paso del Buey Negro, *d*–*f* Río Cuareim outcrops, *g* Arroyo Malo). Stars indicate outcrops with *Castrichnus*. **c**–**d** outcrops of the Sopas Formation (Arroyo Sopas and Río Cuareim respectively)

2 Geographic and Geological Setting

The Sopas Formation crops out in northern Uruguay (Artigas, Salto, Tacuarembó, Paysandú, and Río Negro departments) alongside creeks and rivers and has a patchy pattern of distribution (Ubilla et al. 2004) (Fig. 1a, b). Lithological features of the analyzed outcrops have been considered in detail in Ubilla et al. (2004) and Goso and Ubilla (2004). In general, the Sopas Formation is composed of medium to coarse sandy and conglomerate basal levels belonging to fluvial facies overlain by brownish mudstones and siltstones related to floodplains deposits, and the evolution of paleosols including occasionally important levels of bioturbation. Antón (1975) described the coarse and sandy levels as the Mataojo Formation and the mudstones as the Sopas Formation. Panario and Gutiérrez (1999) and Panario et al. (2014) referred this unit to the Dolores-Sopas Formation.

The outcrops considered here are located in the following localities: Artigas: Paso del León, Mina 1, Estiba, Piedra Pintada (Río Cuareim), and Arroyo Yucutujá; Salto: Paso del Buey Negro (Río Arapey Chico), Río Arapey Grande, Arroyo Sopas, Arroyo Arerunguá, Cañada Sarandí, Ofelia Pliegas; Tacuarembó: Paso Colman, Lavié I y II (Arroyo Malo); Paysandú: Río Queguay; Río Negro: Arroyo Tres Árboles. The most studied localities are indicated in Fig. 1.

3 Materials and Methods

Samples for ^{14}C and OSL ages were taken following protocols indicated by laboratories. Calibrated ages provided in this paper were calculated using Calib 2013 including the SHCal-13 option (Stuiver et al. 2103; Hogg et al. 2013). In addition, calibrated ^{14}C and OSL ages included in Tables 1 and 2 have GPS localization data, but this information is not provided here in order to avoid depredation of fossiliferous sites. A database of the fossil content of the Sopas Formation was generated considering the specimens housed in institutional and particular collections (1053 bone remains). The contribution of each family to the **NISP** (total number of identified specimens) was quantified for mammals (Fig. 2).

4 Numerical Ages

Ubilla and Perea (1999); Ubilla et al. (2004) and Martínez and Ubilla (2004) provided some numerical ages for the Sopas Formation based on ^{14}C and TL/OSL methods. Other ages from several fossiliferous localities were obtained in the last years. All these data are compiled and analyzed here in order to build a chronologically congruent pattern (Tables 1 and 2; Appendices 1–2).

4.1 ^{14}C Ages

Recently, many finite ages based on the radiocarbon method were obtained together with minimum ages (Table 1). The samples used were wood, fresh-water mollusk shells, teeth, and bones.

From the Arroyo Malo locality many ages based on *Diplodon* shells are interpreted as minimum ages (>45 ka B.P.). However, overlying the *Diplodon* bed, we recently obtained for the first time, five finite and stratigraphically ordered ages ranging from 33,560 ± 700 year B.P. (cal 36,089−39,426 year) to 39,900 ± 1,100 (cal 42,025 −45,389 year) based on *Cyanocyclas* sp. (=*Neocorbicula*) and *Pomacea* sp. shells. These ages should be considered together with the OSL of 58–32 ka ages from the same outcrops (see below and Table 2). Two ages based on the bone mineral fraction (16,460 ± 185 year B.P.; 18,650 ± 160 year B.P.) and spatially associated with ^{14}C shell and OSL ages are totally contradictory and interpreted by laboratories as minimum ages.

In the Río Cuareim outcrops were obtained based on woods more minimum ages (>45 ka B.P.). But, there are two ages of 12,100 ± 140 year B.P. (cal 13,550–14,373 year) and 13,869 ± 54 year B.P. (cal 16,473−16,983 year) based on wood samples that came from younger facies of the Sopas Formation with very scarce fossiliferous content.

From the Cañada Sarandí (Salto) locality were obtained based on woods' minimum ages. The age of 5,599 ± 58 year B.P. based on tooth enamel of *Hippidion* cf. *H. principale* from the Paso del Buey Negro (Salto) is rejected at first glance because it is too recent and cannot be explained in the stratigraphic context (see below). In addition, an age of 12,502 ± 55 year B.P. (cal 14,234−15,001 year) from Arroyo Tres Arboles (Río Negro) was recently obtained (shell of *Cyanocyclas* sp.) associated with some extinct mammals (such as deer *Antifer* and glyptodonts).

Archeological studies performed in northern Uruguay provided several ^{14}C ages ranging from approximately 11–8.5 ka (Suárez 2011; Suárez and Santos 2010; Suárez and López 2003; López 2013; Castiñeira et al. 2010, and references therein). *Equus* sp. and *Glyptodon* sp. were reported in association with anthropogenic lithic materials in a 9,585–9,525 year B.P. level (Suárez 2011). A calibration of the 11,200 ± 500 year B.P. age (MEC 1989) provided a 2 sigma cal B.P. 11,600–14,176 year, a roughly similar age with regard to the aforementioned result for Río Cuareim in northern Uruguay (cal 13,550–14,373 year). Nevertheless, authors did not refer the sedimentary context to the Sopas Formation, except for Castiñeira et al. (2010) who related part of the analyzed sequences to this unit.

4.2 OSL/TL Ages

The sampling performed in order to produce OSL/TL ages (Table 2) was focused mainly on fossiliferous outcrops and particularly in localities with radiocarbon

Table 1 ^{14}**C** conventional and **AMS*** ages from the Sopas Formation

ID lab.	Taxon sample	Locality	^{14}C age B.P. (cal B.P., 2 sigma)	Source
AA101332*	*Hippidion* (FCDPV-2450) Enamel	Buey Negro, Arapey chico, Salto	**5,599 ± 58**	**This paper**
LP-594	Wood indet	Estiba Rio Cuareim, Artigas	**12,100 ± 140 (13,550–14,373)**	Ubilla et al. (2004)
AA104912*	*Cyanocyclas* sp. shell	Arroyo 3 Árboles, Río Negro	**12,502 ± 55 (14,234–15,001)**	**This paper**
AA99843*	Wood indet	Minal, Rio Cuareim, Artigas	**13,869 ± 54 (16,473–16,983)**	**This paper**
GX-19272	Deer indet apatite	Arroyo Malo, Tacuarembó	**16,460 ± 185**	Ubilla (2001)
URU-0035	*Glyptodon* sp. mineral	Arroyo Malo, Tacuarembó	**18,650 ± 160**	Ubilla (2001)
AA104915*	*Pomacea* sp. shell	Arroyo Malo, Tacuarembó	**33,560 ± 700 (36,089–39,426)**	**This paper**
AA101329*	*Pomacea* sp. shell	Arroyo Malo, Tacuarembó	**35,530 ± 680 (38,659–41,421)**	**This paper**
AA104914*	*Pomacea* sp. shell	Arroyo Malo, Tacuarembó	**37,070 ± 810 (39,940–42,665)**	**This paper**
AA104913*	*Pomacea* sp. shell	Arroyo Malo, Tacuarembó	**38,300 ± 940 (40,865–43,932)**	**This paper**
AA104911*	*Cyanocyclas* sp. shell	Arroyo Malo, Tacuarembó	**39,900 ± 1,100 (42,025–45,389)**	**This paper**
AA101328*	*Diplodon* 1 shell	Arroyo Malo, Tacuarembó	**>45,200**	**This paper**
URU-0032	*D. peraeformis* shell	Arroyo Malo, Tacuarembó	**>45,000**	Ubilla and Perea (1999)
URU-0031	*D. peraeformis* shell	Arroyo Malo, Tacuarembó	**>45,000**	Ubilla and Perea (1999)
URU-0053	*Prosopis nigra* wood	Cañada Sarandí, Salto	**>45,000**	Ubilla and Perea (1999)
LP-490	*Prosopis* sp. wood	Piedra Pintada, Río Cuareim	**>43,000**	Ubilla and Perea (1999)
URU-0036	*Prosopis* sp. wood	Piedra Pintada, Río Cuareim	**>45,000**	Ubilla and Perea (1999)

(continued)

Table 1 (continued)

ID lab.	Taxon sample	Locality	^{14}C age B.P. (cal B.P., 2 sigma)	Source
AA101327*	Deer indet. (FCDPV-2768) enamel	Arroyo Malo, Tacuarembó	–	**This paper**
AA101331*	Ground-sloth (FCDPV-2571) ossicles	Arapey Chico,Salto	–	**This paper**
AA101330*	Deer indet. (FCDPV-2769) enamel	Arroyo Malo, Tacuarembó	–	**This paper**

^{13}C information available is provided

* to highlight which samples were dated using AMS method. All the samples without the asterisk were dated using conventional radiocarbon method

information. There are several ages that seem to be stratigraphically congruent. Nevertheless, in the available set some stratigraphic inversions were detected.

In the Arroyo Malo outcrops, ages were obtained ranging from 58,300 ± 7,400 to 32,850 ± 1,990 year. The first age mentioned here was obtained from a sample associated with the >45 ka B.P. radiocarbon ages from the *Diplodon* bed, in addition to the 34,405 ± 2,240 year sample from an overlying bed. The two OSL ages of 32 ka are based on samples taken from an overlying bed to the *Pomacea* sp. ages (cal 36,089−39,426 to 40,865−43,932 year). There are two ages of 200 and 314 ka that differ from the general pattern observed, belonging to the profiles with 58 and 32 ka, respectively, but with stratigraphic inversion. These ages are rejected taken into account the aforementioned radiocarbon and OSL information.

The base of the profile of the Arroyo Sopas, yielded an age of 43,500 ± 3,600 year and an age of 30,600 ± 5,400 year based on a sample taken from paleocave infilling sediment (Prosul 2009–2011). There are two contradictory results (14,485 ± 1,240 and 36,900 ± 6,500 year) from Paso del Buey Negro. The samples were collected from the same level, so it is necessary to increase the number of samples in future studies.

Many ages were obtained from different localities of the Río Cuareim. In Paso del León locality, the ages obtained (30,300 ± 3,700 and 71,400 ± 11,000 year) are stratigraphically inverted. At Mina 1, fossiliferous levels yielded an age of 36,100 ± 6,200 year (Prosul 2009–2011). An age of 27,400 ± 3,300 year was obtained in an isolated outcrop, of non-fossiliferous coarse beds. The age of 96,000 ± 11,000 year is based on a sample taken from an outcrop without fossil content, which seems to be an older stratigraphic bed of the Sopas Formation. The

Table 2 OSL ages from the Sopas Formation

ID lab.	Sample	Sample location	OSL Age (year)[a]	Source
UIC-3455	Medium sandy	Buey Negro, Río Arapey chico, Salto	**14,485 ± 1,240**	**This paper**
LVD-1449	Medium to coarse sandy	Río Cuareim, Artigas	**27,400 ± 3,300**	**This paper**
LVD-2657	Silty sandy	Paso del León, Río Cuareim, Artigas	**30,300 ± 3,700**	Prosul (2009–2011)
LVD-2660	Sandy-silt crotovina	Arroyo Sopas, Salto	**30,600 ± 5,400**	Prosul (2009–2011)
UIC-3458	Medium sandy	Arroyo Malo, Tacuarembó, Lavie II	**32,850 ± 1,990**	**This paper**
UIC-3451	Medium to coarse sandy	Arroyo Malo, Tacuarembó. P. Colman	**32,995 ± 1,930**	**This paper**
UIC-3332	Medium sandy	Arroyo Malo, Tacuarembó, Lavie II	**34,405 ± 2,240**	**This paper**
LVD-2655	Silty sandy	Mina 1, Río Cuareim, Artigas	**36,100 ± 6,200**	Prosul (2009–2011)
LVD-2661	Médium sandy	Buey Negro, Río Arapey chico, Salto	**36,900 ± 6,500**	Prosul (2009–2011)
LVD-647	Sandy-silt	Arroyo Sopas, Salto	**43,500 ± 3,600**	Ubilla (2004), Ubilla et al. (2004)
LVD-646	Sandy-silt	Arroyo Malo, Tacuarembó, Lavie II	**58,300 ± 7,400**	Ubilla (2004), Ubilla et al. (2004)
LVD-2658	Silty sandy	Paso del León, Río Cuareim, Artigas	**71,400 ± 11,000**	Prosul (2009–2011)
LVD-1241	Medium sandy	Río Cuareim, Artigas	**96,000 ± 11,000**	**This paper**
LVD-859	Sandy-silt	Piedra Pintada, Río Cuareim, Artigas	**180,000 ± 20,000**	Martínez and Ubilla (2004)
LVD-857	Silt	Arroyo Malo, Tacuarembó. Lavie II	**200,000 ± 25,000**	Martínez and Ubilla (2004)
LVD-2659	Silty sandy	Piedra Pintada, Río Cuareim, Artigas	**248,000 ± 26,000**	Prosul (2009–2011)
LVD-1242	Sandy-silt	Arroyo Malo, Tacuarembó. P.Colman	**314,000 ± 39,300**	**This paper**
LVD-858	Fine sandy	Piedra Pintada, Río Cuareim, Artigas	**360,000 ± 40,000**	Martínez and Ubilla (2004)

[a] For UIC ages, all errors are at one sigma and ages are calculated from AD 2010

fossiliferous locality Piedra Pintada deserves particular consideration, with ages of 360, 248 and 180 ka, that are stratigraphically coherent, which are not only clearly older than MIS 3 but also than the Last Interglacial. They are related to >45 ka B. P. radiocarbon ages (wood) and totally depart from the global pattern obtained. It is very difficult to explain these results, which should be taken with caution awaiting further analysis. It is important to highlight that the mammalian content does not differ from the other outcrops of the unit.

5 Paleontological Content

In this section, the taxonomic information of the Sopas Formation is summarized and updated (Tables 3 and 4), associated with the environmental and climatic signals provided by the various taxa identified.

5.1 Trace Fossils

This type of fossil is represented in the Arroyo Sopas locality by some burrow-like structures found associated with skeletal remains of the extinct caviine *Microcavia criolloensis* (Ubilla et al. 1999), which could be the trace-producer (Ubilla 2008). Other structures interpreted as large paleocaves were also found in the same strata. A few coprolites have been reported (Piedra Pintada, Río Cuareim) and related to medium to large predators based on their shape and caviine bones and teeth inclusions (Verde and Ubilla 2002). The hypercarnivorous canids, such as *Protocyon* or *Dusicyon avus* (Prevosti et al. 2009), could also be considered as possible producers. Other authors (Chimento and Rey 2008) claim a canid origin of these materials.

Table 3 Updated list of non-mammals vertebrates for the Sopas Formation of northern Uruguay. Based on Ubilla et al. (2004), Tambussi et al. (2005, 2009) and this paper

Teleostei
Paracanthopterygii/Acanthopterygii indet.
Testudines
Family **Testudinidae**
Chelonoides sp. Fitzgerald, 1835
Squamata
Family **Teiidae**
Tupinambis cf. *T. teguixin* (Linnaeus 1766)
Aves
Family **Rheidae**
Rhea sp. Brisson 1760
Family **Anatidae**
Chloephaga picta (Gmelin 1789)
Family **Cariamidae**
Cariama cristata (Linnaeus 1766)
Family **Psitaciidae**
Cyanoliseus patagonus (Vieillot 1817)
Family **Furnariidae**
cf. *Pseudoseisuropsis* sp. Noriega (1991)

Table 4 Updated list of mammals for the Sopas Formation of northern Uruguay

Order Didelphimorphia	Family **Caviidae**
Family Didelphidae	[a]*Cavia* sp. Pallas, 1766
[ac]cf. *Didelphis* sp. Linneus, 1758	[ac]*Galea* sp. Meyen, 1831
	[bc]*Microcavia criolloensis* Ubilla et al., (1999)
Order Xenarthra	[a]*Dolichotis* sp. Desmarest, 1820
Family **Dasypodidae**	[a]*Hydrochoerus hydrochaeris* (Linnaeus, 1766)
[ac]*Dasypus* aff. *D. novemcinctus* Linnaeus, 1758	*Neochoerus* cf. *N. aesopi* (Leidy, 1853)
Propraopus sp. Ameghino, 1881	
Family **Pampatheriidae**	**Order Litopterna**
Pampatherium typum Gervais and Ameghino, 1880	Family **Macraucheniidae**
Pampatherium humboldti (Lund, 1839)	*Macrauchenia patachonica* Owen, 1838
Family **Glyptodontidae**	Family **Proterotheriidae**
Glyptodon clavipes Owen, 1839	[c]*Neolicaphrium recens* Frenguelli, 1921
[c]cf. *Hoplophorus* Lund, 1839	*N.* cf. *N. recens*
Neuryurus rudis (Gervais, 1878)	
Panochthus tuberculatus (Owen, 1845)	**Order Notoungulata**
Family **Megatheriidae**	Family **Toxodontidae**
Megatherium americanum Cuvier, 1796	*Toxodon* cf. *T. platensis* Owen, 1837
Family **Nothrotheriidae**	
[c]*Nothrotherium* cf. *N. maquinense* (Lund, 1838)	**Order Proboscidea**
Family **Mylodontidae**	Family **Gomphotheriidae** gen. et sp. indet.
Glossotherium robustum (Owen, 1842)	
Lestodon armatus Gervais, 1855	**Order Perissodactyla**
[c]*Catonyx cuvieri* (Lund, 1839)	Family **Tapiridae**
[c]*Catonyx* sp. Ameghino. 1891	[a]*Tapirus terrestris* (Linnaeus, 1758)
Subfamily Scelidotheriinae gen. et sp. indet.	[c]*Tapirus* sp.
	Family **Equidae**
Order Carnivora	[b]*Equus (Amerhippus) neogeus* Lund, 1840
Family **Canidae**	*Hippidion principale* (Lund, 1845)
[ac]*Lycalopex gymnocercus* (Fischer, 1814)	
[c]*Dusicyon avus* (Burmeister, 1866)	**Order Artiodactyla**

(continued)

Table 4 (continued)

[c]*Protocyon troglodytes* Lund, 1838	Family **Tayassuidae**
Family **Felidae**	[ac]*Tayassu pecari* (Link, 1795)
[ac]*Felis concolor* Linnaeus, 1771	[ac]*Catagonus* wagneri (Rusconi, 1930)
[a]*Panthera* cf. *P.onca* (Linnaeus, 1758)	[bc]*Catagonus stenocephalus* (Lund in Reinhardt, 1880)
Smilodon populator Lund, 1842	Family **Cervidae**
Family **Mustelidae**	*Antifer ultra* (Ameghino, 1888)
[ac]*Lontra longicaudis* (Olfers, 1818)	[a]*Ozotoceros* aff. *O. bezoarticus* (Linnaeus, 1758)
Family **Ursidae**	*Morenelaphus brachyceros* (Gervais and Ameghino, 1880)
Arctotherium aff. *A. bonariense* (Gervais, 1852)	*Morenelaphus lujanensis* (Ameghino, 1888)
Order Rodentia	[c]*Paraceros fragilis* (Ameghino, 1888) [c]*Mazama* sp. Rafinesque, 1817
Family **Cricetidae**	Family **Camelidae**
[ac]*Reithrodon* sp. Waterhouse, 1837	*Hemiauchenia paradoxa* Gervais and Ameghino, 1880
[ac]cf. *Wilfredomys oenax* (Thomas, 1928)	[a]*Lama guanicoe* (Müller, 1776)
[a]*Lundomys molitor* (Winge, 1887)	*Palaeolama major* (Liais, 1872)
Family **Erethizontidae**	[a]*Vicugna vicugna* (Molina, 1782)
[b]*Coendou magnus* (Lund, 1839)	
Coendou cf. *C. magnus*	
Family **Echimyidae**	
Myocastor coypus (Molina, 1782)	
Family **Chinchillidae**	
Lagostomus sp. Brookes, 1828	

Based on Ubilla et al. (2004, 2009, 2011and references therein), Prevosti et al. (2009), Perea (2008), Gasparini et al. (2009, 2013), Corona (2012), Scherer (2009), and this paper
[a]Extant at generic or specific level
[b]Extinct species of extant genus
[c]Found in a single locality

The most frequent type of trace fossil is represented by *Castrichnus incolumis*, as described by Verde et al. (2007) and interpreted as earthworm aestivation chambers produced in soils (Fig. 3a). They were found in various localities (the Arroyo Sopas and Arroyo Arerunguá, Ofelia Pliegas, Arroyo Malo, and Río Queguay) (Fig. 1b). According to Verde et al. (2007), these trace fossils suggest a seasonal climate. This inference is based on the fact that some living earthworms construct identical chambers during the summer to avoid desiccation (Verde et al. 2007). Recently, Genise et al. (2013) described an identical chamber from a living earthworm in Misiones, Argentina, a subtropical rainforest area of South America. These authors stated that *Castrichnus* could be produced not only during a seasonal climate, but also when marked droughts occur. The chambers were produced during an atypical drought period in a region that lacks seasonal climate. In this sense, *C. incolumis* could indicate drought conditions even if a seasonal climate is lacking (Genise et al. 2013). Because these types of traces found in various localities in northern Uruguay require special preservation contexts, they suggest that a similar climate and environments could be involved among these different outcrops.

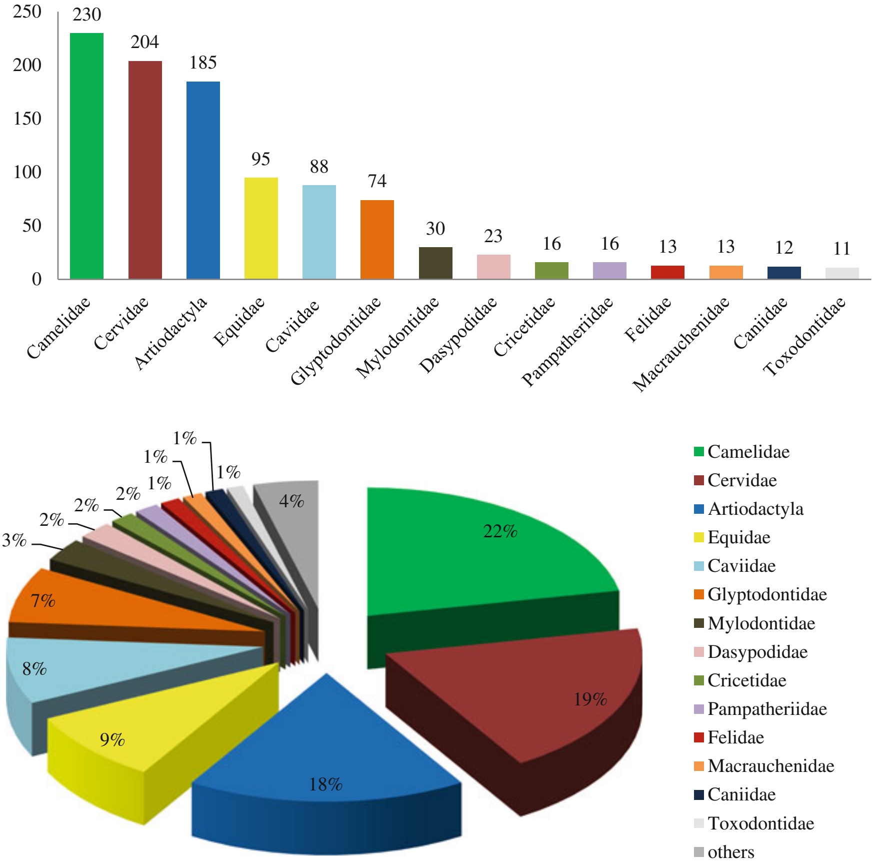

Fig. 2 *Above* Total number of identified specimens (NISP) per Family of mammals (equal or more than 1 %). *Below* Percentage of contribution per family to the total number

5.2 Wood

Very few wood remains have been found in the Sopas Formation until now (Ubilla et al. 2004; Martínez and Ubilla 2004). Though very limited information can be obtained from the available remains, some were determined as *Prosopis* (Inda and del Puerto 2002). This tree is widespread today in tropical to subtropical areas of South America, having also adapted to live in arid to semiarid soils, and proving that it is drought-resistant.

5.3 Mollusks

Fresh-water bivalves and gastropods and also a few terrestrial snails were reported for some localities of the Sopas Formation (Martínez and Rojas 2004). Bivalves are frequently found with articulated valves and gastropods are usually complete. These mollusks can be found in several localities (Arroyo Tres Árboles, Arroyo Malo, Arroyo Arerunguá, Arroyo Sopas, Arroyo Yucutujá among others). They indicate the presence of fluvial and lacustrine contexts.

5.4 Vertebrates

The vertebrates recorded in the Sopas Formation are represented by a few Teleostei indet, reptiles, and avian taxa (Table 3) and numerous mammals (Table 4). Reptiles include the large extinct terrestrial tortoise *Chelonoides* and various non-determined small turtles along with the teiid *Tupinambis* cf. *T. teguixin*. The avian taxa, even if only a few, provide interesting environmental and climatic evidences. *Rhea* and *Cariama* are indicators of open, semi-open, and wooded areas (*Cariama* needs trees to nest) (Ubilla et al. 2004; Tambussi et al. 2005). Fresh-water environments are inferred from the presence of *Chloephaga picta* (Tambussi et al. 2005) which are also indicated by the aforementioned association of mollusks in some localities. It is a southern South American species that migrates during winter to northern latitudes, up to the southern border of Uruguay. According to this record in north-central Uruguay (Tacuarembó), this anatid occupied more northern locations during the Late Pleistocene. It also indicates seasonality.

A new avian record for the Arroyo Sopas is herein reported. It is a furnariid likely belonging to the genus *Pseudoseisuropsis* that was previously referred to late Pleistocene sediments in southern Uruguay (*P. cuelloi;* Claramunt and Rinderknecht 2005). Terrestrial habits related to open and semiarid environments were inferred for *P. nehuen* (Early to Middle Pleistocene of Argentina) (Noriega 1991) and most likely similar conditions for *P. cuelloi* (Claramunt and Rinderknecht 2005).

Mammals are the dominant group, including 25 families in nine orders encompassing more than 50 species (Table 4). Many extinct taxa and also extinct species of living genera are recorded. There are some taxa not represented in the current communities of Uruguay but living today in other areas of South America showing local extinction and shifting ranges. Since the publication of Ubilla and Perea (1999), Ubilla (2004) and Ubilla et al. (2004), the diversity at the generic and specific level for the Sopas Formation has been significantly augmented by new findings (Table 4). Counting all the available specimens, the most abundant families are Camelidae, Cervidae, Equidae, Caviidae, and Glyptodontidae, reaching over 60 % of the NISP (Fig. 2). Actually, more than 50 % of the bones include the first two families and selenodont artiodactyls (18 %) whose characteristics do not allow a more specific taxonomic assignment. It has to be taken into account that the number of glyptodont bones is largely increased because of the large amount of osteoderms of their carapace.

The following taxa are firstly reported: an opossum, likely *Didelphis* (Arroyo Sopas and Paso del Buey Negro) which is part of an ongoing study; the pampatheriid *Pampatherium typum* (Arroyo Sopas) and the presence of the glyptodont *Hoplophorus,* though this finding must be confirmed (Paso del Buey Negro). This latter fossil is important because until today, it was considered restricted to the intertropical region of South America (Minas Gerais, Brazil; Porpino et al. 2010) (Fig. 3c). Surprisingly, the glyptodont *Doedicurus* has not been found yet in this unit. The ground-sloth *Catonyx* was recently found in the Sopas Formation (Corona 2012). New remains under study (upper dentition and mandible) allow confirmation that this is *C. cuvieri*, a species recorded in southeastern Brazil and southern Uruguay (Corona et al. 2013) (Fig. 3d). It is very likely that *C. cuvieri* inhabited forested areas. The first dental material of the short-faced bear *Arctotherium* aff. *A. bonariense* was discovered in the Paso del Buey Negro locality (L. Soibelzon, pers. comm. 2014) (Fig. 3b). Notably, various postcranial bones of a small to medium size bear were also found. The predator guild is also represented not only by medium to large felids but also by large and hypercanivorous canids, such as *Dusicyon* and *Protocyon* (Prevosti et al. 2009). Caviidae are well represented in the Sopas Formation, and the presence of *Dolichotis* (almost complete skull) in the Río Arapey Grande is herein confirmed (Fig. 3e).

Recently, Ubilla et al. (2011) described the first cranial remains of the extinct proterotheriid *Neolicaphrium* cf. *N. recens*. This taxon is now recorded in the Arroyo Malo, Arroyo Sopas and the Mina 1 localities. The record of peccaries was notably increased by the description of two new taxa for this unit: *Catagonus wagneri* and *C. stenocephalus,* which have important climatic and environmental significance (Gasparini et al. 2011, 2013); the presence of *Tayassu pecari* has been confirmed (Gasparini et al. 2009). This implies the presence of three species of peccaries in the same unit, which is certainly unusual in the fossil record of these mammals in South America.

The small deer *Mazama* was found in the Paso del Buey Negro locality (Fig. 3f). Today, this small deer is predominantly an inhabitant of closed forested environments. Recent reviews of camelids (Lorenzo 2009; Scherer 2009) modified the

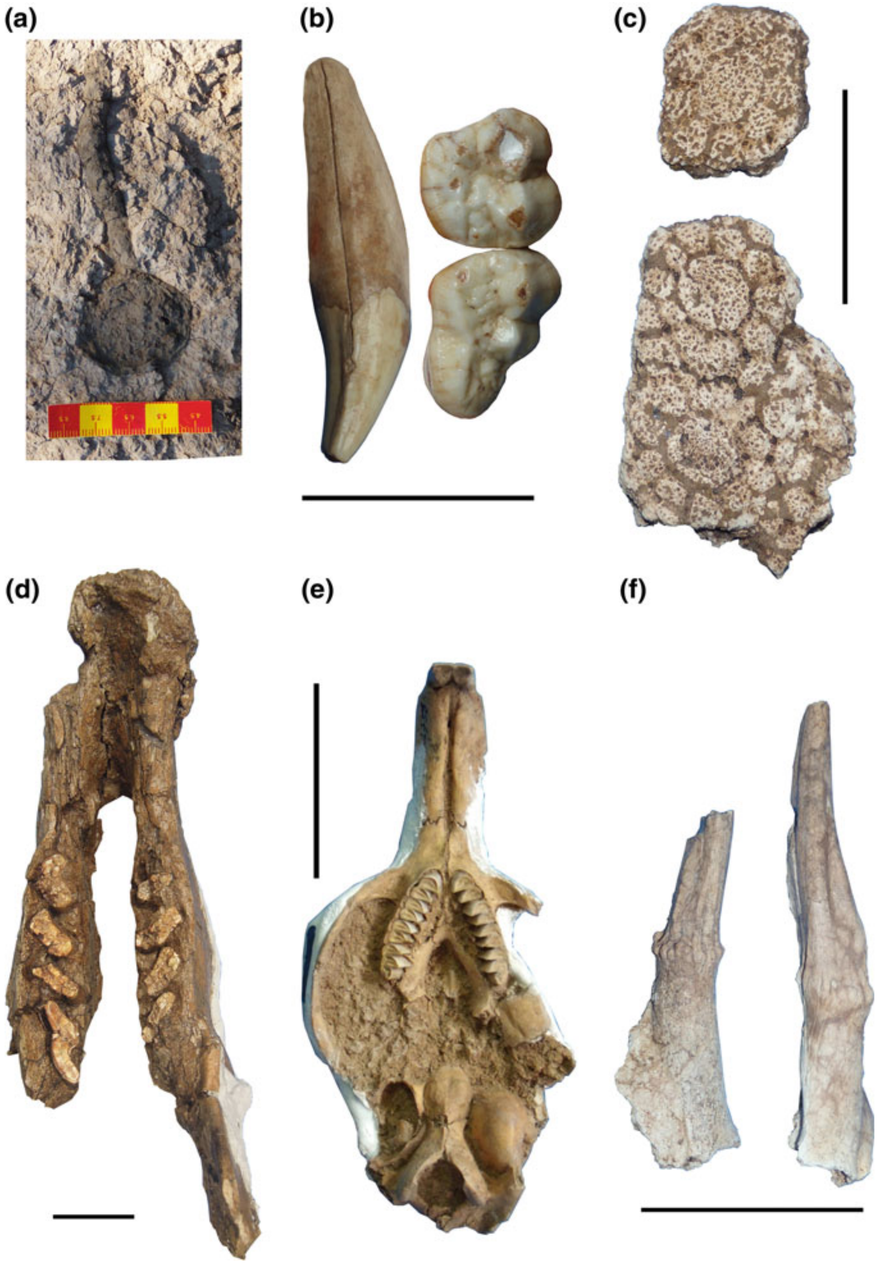

Fig. 3 **a** *Castrichnus incolumis*, **b** *Arctotherium* aff. *A. bonariense,* **c** cf. *Hoplohophorus* sp., **d** *Catonyx cuvieri*, **e** *Dolichotis* sp., **f** *Mazama* sp. **b–e** scale: 5 cm

taxonomic records of this group in the Sopas Formation, which are represented by *Lama guanicoe*, *Vicugna vicugna*, and *Palaeolama major*, in addition to *Hemiauchenia paradoxa*.

The "Paso del Buey Negro" at Río Arapey Chico (Salto department) (Fig. 1) is a new locality under study that deserves particular consideration. Sedimentary features are dominated by medium sandy basal levels that can laterally change to coarser beds, and mudstone strata in the uppermost portion of the outcrops. In these outcrops, very well-preserved bones of horses (*Hippidion* cf. *H. principale* and *Equus neogaeus*), including skulls, mandibles, and partially articulated postcranial bones have been found; isolated teeth of *Tapirus* sp. and remains of capybaras (*Hydrochoerus* sp.) belonging to juvenile and adults are frequently found. A few sigmodontine mandibles, the ground-sloth *Glossotherium,* grace postcranial remains of a nothrotherid sloth, peccaries similar to *Tayassu pecari,* small camelids very similar to the vicugna, antlers of *Antifer* and *Mazama* and the aforementioned teeth of *Arctotherium* cf. *A. bonariense* have been identified. This mammalian assemblage includes taxa that indicate fluvial environments along with forested to semi-forested areas; some taxa are related to tropical to temperate contexts. However, the numerical ages yield contradictory information (see Tables 1 and 2) that should be revised.

The first dental enamel $\delta^{13}C$ isotope data were provided for some ungulates (*Hippidion* cf. *H. principale*, *Equus neogaeus*, undetermined deer and a large camelid), forming part of an ongoing study (Morosi and Ubilla 2014). Predominantly browser to mixed feeding habits have been inferred, likely related to open to semi-open environments, and noticeably, no values of C_4 grassers were obtained (Morosi and Ubilla 2014).

6 Discussion

Evidence favoring correlation with the MIS 3 is discussed here, taking into account the numerical ages, the information provided by the trace fossils and the body fossil content.

The climatic/chronological pattern of the MIS 3 is well substantiated by northern hemisphere, and the various stadials (colder intervals) and interstadials (warmer intervals) are well-characterized (Van Meerbeeck et al. 2009, 2011; Rabassa and Ponce 2013; Long and Stoy 2013, among others). There are efforts to identify these events and to understand the influence of the MIS 3 in the southern hemisphere (EPICA 2006; Jouzel et al. 2007; Hodgson et al. 2009; Tonni et al. 2010; Buiron et al. 2012; Paisani et al. 2014; Gottschalk et al. 2014, among others) and inter-hemispheric connections based on Greenland–Antarctic ice-core studies (EPICA 2006; Jouzel et al. 2007). A bipolar thermal seesaw was proposed, and northern hemispheric colder events (Greenland cores) might be related to the southern hemispheric warmer events (Antarctic cores) and vice versa (EPICA 2006; Orombelli et al. 2010; Hessler et al. 2011). However, Jouzel et al. (2007), using a

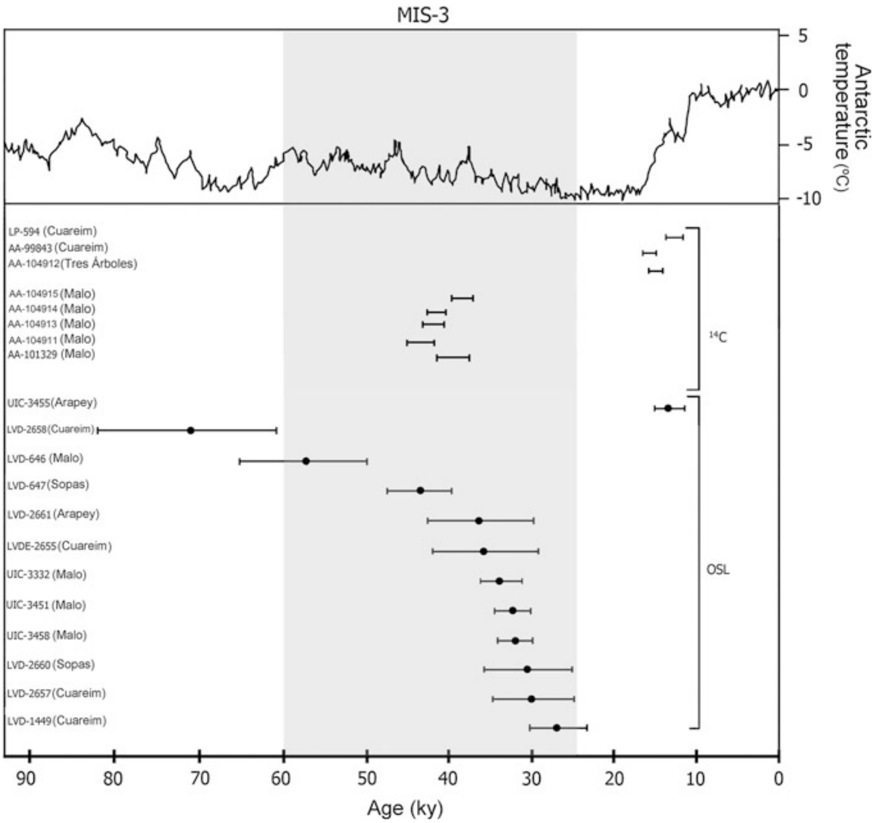

Fig. 4 *Above* The Antarctic climatic variation in the last 90 ka (redrawn from Jouzel et al. 2007). *Below* cal ^{14}C and OSL ages from the Sopas Formation and their relationships with the MIS 3 and latest Pleistocene. Horizontal bars in OSL ages indicate range

more precise calibration, claim that there is a correspondence between the warmer events in the northern hemisphere and major warmer events in Antarctica.

Aside from the three ages based on wood and shell aging with the latest Pleistocene, most radiocarbon data indicate older ages for the fossiliferous beds of the Sopas Formation. In particular, the set of ages ranging from 33,560 ± 700 year B.P. (cal 36,089−39,426 year) to 39,900 ± 1,100 (cal 42,025−45,389 year) from the Arroyo Malo locality is indicative of MIS 3 (Fig. 4). The set of TL/OSL samples taken from various outcrops of the Sopas Formation (Arroyo Malo, Arroyo Sopas, and Río Cuareim localities) also supports relationships with the MIS 3 (27,400 ± 3,300 to 71,400 ± 11,000 year) (Fig. 4). Most ages fall in the 50–25 ka time interval and it is more frequently represented the 45–28 ka time interval that includes various events in the northern and southern hemispheres (EPICA 2006; Jouzel et al. 2007; Van Meerbeeck et al. 2009; Buiron et al. 2012) (Fig. 4). The oldest samples, particularly those that are stratigraphically inverted, that depart from this chronological pattern should be considered with caution or rejected.

As it can be expected about a fluvial context, a time-averaging pattern that affects the preservation context should be assumed (Beherensmeyer et al. 2000; Ubilla et al. 2004). This can be the case for some outcrops of the Sopas Formation such as the Arroyo Malo and Paso del Buey Negro localities. In addition, geographically separated outcrops can yield different ages. In the Arroyo Sopas outcrops, when the numerical ages and the preservation pattern (bones and trace fossils associated) are taken into account, it seems that a shorter time lapse is involved. The peculiar preservation of *Castrichnus*, recorded in several outcrops, can also suggest a similar climate and environment involved in the bearing strata (Fig. 1).

Living representatives of taxa that suggest benign climatic condition (mostly tropical to temperate climates) are recorded in the mammalian assemblage. Tapirs, coendus, coypus, capybaras, river-otters, some peccaries, ocelots, and marsh-rats today inhabit tropical to temperate areas in South America. Some of these taxa also indicate fresh-water bodies along with semi-open to open context. *Rhea* is an inhabitant of open environments and *Cariama* indicates the presence of trees according to its nesting behavior; *Chlohephaga* associated with mollusks indicate fresh-water bodies. Among the extinct taxa, some of them such as some glyptodonts, both horse clades, *Macrauchenia* and *Neolicaphrium,* among others, are indicators of open to semi-open environments. The presence of this mammal assemblage at this latitude of South America in the Late Pleistocene was attributed to the influence of the Last Interglacial or the Last Interstadial, which is correlated to the MIS 3 (Ubilla et al. 2004).

On the other hand, there are some taxa that suggest arid to semiarid environments, such as some caviids (*Dolichotis, Microcavia*), some peccaries (such as *C. wagneri),* and representatives of camelids. To make things more difficult, in some outcrops (e.g., Arroyo Malo locality) we recorded representatives of tropical to temperate conditions (tapirs, marsh-rat, coendu, and river-otter) together with winter migrants such as *Chloephaga*. As previously mentioned, seasonality is substantiated by *Chloephaga* and the worm aestivation chambers. The worm traces could also indicate periods of drought.

This complex climatic and environmental pattern revealed by the fossil content of the Sopas Formation could have been driven by millennial climatic changes that were prevalent during the MIS 3. Various available ^{14}C and OSL ages that span the interval of the MIS 3 favor this hypothesis (Fig. 4).

A faunal replacement model should take into account that the alternating conditions that characterized the MIS 3 cannot be read in the profiles due to a time-averaging effect that produced an "amalgamated" fossil pattern. It must be noted that the MIS 3 formed part of the Last Glacial Cycle that was certainly colder than the Last Interglacial and the current times. The presence in the mammalian assemblage of tropical to subtropical representatives is not predicted by the postulated climatic characteristics of the MIS 3, leaving this issue open to discussion.

An alternative view to the replacement faunal model could take into account that the occurrence of tropical to temperate mammals in the Sopas Formation was facilitated when the warmer Last Interglacial (MIS 5) conditions were prevalent at this latitude. The subsequent interval of time implies colder climate that could have paved the way for the widespread of cold- and arid-adapted mammals, resulting in mixed climatic faunas. Noticeably, Alvarez-Lao (2014) described a mixed cold and temperate fauna (Iberian Peninsula) in the interval 36–30 ka as a consequence of the MIS 3 influence. The survival of tropical to temperate mammals during the MIS 3 at this latitude could have been caused by the presence of permanent streams, riparian forest, and semi-forested areas and the relatively warmer conditions established during the D-O events. Southern Brazil (Araucaria Plateau) seems to have had grasslands and savannahs in the 45–34 ka and forest in the 33–28 ka interval of time (Paisani et al. 2014). In addition, these tropical to temperate mammals are represented in the Sopas Formation by a scarce number of specimens. This pattern could be interpreted as a low abundance in the postulated mixed climatic fauna due to their relict condition. Currently, there are heterogeneous biomes in South America, such as the "Cerrado" (in Brazil), characterized by a mosaic of environments (open habitats, savannahs, and dense woodlands including gallery forests together with permanent streams) under seasonal climate, where forest species coexist with non-forest species (Carmignotto et al. 2012).

Acknowledgments We are indebted to E.P. Tonni and J. Rabassa for inviting us to attend the MIS 3 Symposium at La Plata (2013); G.M. Gasparini helped us in many editorial issues and improvement of the manuscript; L. Soibelzon gave us suggestions about Tremarctinae remains. L. Suárez (Arqueología, FHyCE, Uruguay) provided the useful literature; M. Ghizzoni (Salto) allowed us the access to information about the collection and facilitated the study of comparative material. A. Rojas and S. Martínez assisted us with the taxonomic determination of mollusk samples. E. Morosi helped us in fieldwork. Grants FCE-2009-2398, CSIC C-211-348 (M.Ubilla), and FCE-2011-6752 (D. Perea) supported this research.

Appendix 1: OSL Details According LVD Lab

ID lab	Anual dose uGy/year	Acumulated dose LOE (Gy)	Th (ppm)	U (ppm)	K
LVD-2660	1.366 ± 173	41.84	7.794 ± 0.281	2.255 ± 0.588	–
LVD-2661	1.101 ± 139	40.61	5.504 ± 0.198	1.891 ± 0.482	–
LVD-2655	2.496 ± 307	90.03	6.040 ± 0.217	2.746 ± 0.489	1.107 ± 0.161
LVD-2657	993 ± 70	30.03	3.939 ± 0.142	1.783 ± 0.210	0.036 ± 0.005
LVD-2658	1.483 ± 154	105.89	7.109 ± 0.256	2.492 ± 0.462	0.105 ± 0.015
LVD-2659	928 ± 49	230.38	3.717 ± 0.134	1.741 ± 0.150	–
LVD-1241	603 ± 9	57.9	–	–	–
LVD-1242	774 ± 19	243.7	–	–	–
LVD-1449	1.085 ± 23	29.74	–	–	–
LVD-647	1.237 ± 38.9	53.8	6.36 ± 0.19	1.73 ± 0.04	0.128 ± 0.013
LVD-646	1.073 ± 29.7	62.8	4.88 ± 0.04	1.76 ± 0.04	0.069 ± 0.007

Appendix 2: Optically Stimulated Luminescence Details on Quartz Grains of the Sopas Formation Samples According to Luminescence Dating Research Laboratory, University of Illinois (UIC)

ID lab.	Equivalent dose (Grays)[a]	U (ppm)[b]	Th (ppm)[b]	K_2O (%)[b]	H_2O (%)[c]	Cosmic dose (mGrays/year)[d]	Total dose (mGrays/year)
UIC3332	39.72 ± 2.62	0.9 ± 0.1	2.1 ± 0.1	0.99 ± 0.01	10 ± 3	0.16 ± 0.02	1.15 ± 0.08
UIC3458	45.58 ± 2.78	1.0 ± 0.1	5.0 ± 0.1	0.82 ± 0.01	10 ± 3	0.16 ± 0.02	1.39 ± 0.07
UIC3451	48.66 ± 2.44	2.0 ± 0.1	4.0 ± 0.1	0.82 ± 0.01	10 ± 3	0.14 ± 0.01	1.47 ± 0.07
UIC3455	14.31 ± 0.78	1.7 ± 0.1	3.1 ± 0.1	0.59 ± 0.01	30 ± 5	0.14 ± 0.01	1.20 ± 0.06

[a] Equivalent dose determined by the multiple aliquot regenerative dose method under blue (470 nm) excitation. Blue emissions are measured with 3-mm-thick Schott BG-39 and one, 3-mm-thick Corning 7–59 glass filters that blocks >90 % luminescence emitted below 390 nm and above 490 nm in front of the photomultiplier tube. The coarse-grained (150–250 µm or 425–500 µm) quartz fraction is analyzed

[b] U, Th and K_2O determined by ICP-Ms at Activation Laboratory Ltd., Ontario

[c] Average water content estimated from particle size characteristics assuming periodic wetting in vadose zone

[d] Cosmic dose rate component based on latitude, longitude, elevation, and burial depth of samples

References

Alvarez-Lao D (2014) The Jou Puerta Cave (Asturias, NW Spain): a MIS 3 large mammal assemblage with mixture of cold and temperate elements. Palaeogeogr Palaeoclimatol Palaeoecol 393:1–19

Antón D (1975) Evolución geomorfológica del norte del Uruguay. Dirección de Suelos y Fertilizantes, Ministerio de Agricultura y Pesca, Montevideo

Beherensmeyer A, Kidwell S, Gastaldo R (2000) Taphonomy and paleobiology. Paleobiol 26:103–147

Bombín M (1975) Afinidade paleoecológica, cronológica e estratigráfica do componente de megamamíferos na biota do quaternario terminal da Provincia de Buenos Aires, Uruguai e Rio Grande do Sul (Brasil). Comunicacoes Museum de Ciencias, Pontificia Universidade Católica do Rio Grande do Sul 9:1–28

Buiron D, Stenni B, Chappellaz J, Landais A, Baumgartner M, Bonazza M, Capron E, Frezzotti M, Kageyama M, Lemieux-Dudon B, Masson-Delmotte V, Parrenin F, Schilt A, Selmo E, Severi M, Swingedouw D, Udisti R (2012) Regional imprints of millennial variability during the MIS 3 period around Antarctica. Quat Sci Rev 48:99–112

Carmignotto A, de Vivo M, Langguth A (2012) Mammals of the Cerrado and Caatinga. Distribution patterns of the Tropical open biomes of central South America. In: Patterson B, Costa L (eds) Bones, clones and biomes. The history and geography of recent Neotropical mammals. The University Chicago Press

Castiñeira C, Zárate MA, Blasi A, Fernicola J, del Puerto L, Inda H, Bracco R, García F (2010) Aportes para una actualización de la correlación entre la Formación Sopas del Norte de Uruguay—Formación Luján de la Provincia de Buenos Aires: implicancias arqueológicas. In: Coco G, Feuillet M (eds) Arqueología de Cazadores—Recolectores en la Cuenca del Plata. Centro de Estudios Hispanoamericanos. Ed. Santa Fé

Chimento N, Rey L (2008) Hallazgo de una feca fósil en el Pleistoceno superior—Holoceno inferior del partido de General Guido, provincia de Buenos Aires. Rev Mus Argentino Cienc Nat 10:239–254

Cione A, Tonni EP (1999) Biostratigraphy and chronological scale of uppermost cenozoic in pampean area, Argentina. Quat S Am Antarctic Pen 12:23–51

Claramunt S, Rinderknecht A (2005) A new fossil furnariid from the Pleistocene of Uruguay, with remarks on nasal type, cranial kinetics, and relationships of the extinct genus *Pseudoseisuropsis*. The Condor 107:114–127

Corona A (2012) Los Scelidotheriinae (Xenarthra: Mylodontidae) de Uruguay: sistemática, distribución estratigráfica y cronología. Unpublished dissertation, PEDECIBA Universidad de la República

Corona A, Perea D, McDonald HG (2013) *Catonyx cuvieri* (Xenarthra, Mylodontidae, Scelidotheriinae) from the Late Pleistocene of Uruguay, with comments regarding the systematics of the Subfamily. J Vertebr Paleontol 33(5):1214–1225

EPICA Community Members (2006) One-to-one coupling of glacial climate variability in Greenland and Antarctica. Nature 444:195–198

Gasparini G, Ubilla M, Tonni EP (2009) Tres especies de tayassuidos (*Catagonus wagneri*, *C. stenocephalus* y *Tayassu pecari*) en el Pleistoceno tardío del norte de Uruguay (Fm. Sopas). Reunión Anual Comunicaciones Asoc Paleont Argentina, p 47

Gasparini G, Soibelzon E, Tonni EP, Ubilla M (2011) The "living fossil" Peccary *Catagonus wagneri* (Tayassuidae) and its climatic significance during the Pleistocene and Holocene. Curr Res Pleistocene 28:157–159

Gasparini G, Ubilla M, Tonni EP (2013) The Chacoan peccary, *Catagonus wagneri* (Mammalia, Tayassuidae) in the late Pleistocene (northern Uruguay, South America): Palaeoecological and palaeobiogeographic considerations. Hist Biol 25:679–690

Genise J, Cantil L, Dinghi PA, Sánchez M, Sarzetti L (2013) The aestivation chamber of the giant earthworm *Glossoscolex bergi* (Glossoscolecidae) in the subtropical rainforest of Misiones (Argentina). Ichnos 20:116–119

Goso C, Ubilla M (2004) Los depósitos continentales cuaternarios en el norte de Uruguay: estratigrafía y paleontología. IV Congreso Uruguayo de Geología, Actas 13:1–6

Gottschalk J, Skinner L, Waelbroeck C (2014) Hydrographic changes in the surface ocean of the sb-Antartic Atlantic linked to atmospheric CO_2 variations over the last deglaciation and Marine Isotope Stage 3. Geophys Res Abstr 16

Hessler I, Steinke S, Groeneveld J, Dupont L, Wefer G (2011) Impact of abrupt climate change in the tropical southeast Atlantic during Marine Isotope Stage (MIS) 3. Paleoceanogr. doi:10.1029/2011PA002118

Hodgson D, Verleyen E, Vyverman K, Sabbe M, Leng M, Pickering M, Keely B (2009) A geological constraint on relative sea level in Marine Isotope Stage 3 in the Larsemann Hills, Lambert Glacier region, East Antarctica (31366-33228 cal year BP). Quat Sci Rev 28:2689–2696

Hogg A, Hua Q, Blackwell P, Niu M, Buck C, Guilderson T, Heaton T, Palmer L, Reimer P, Reimer R, Turney C, Zimmerman S (2013) SHCAL 13 southern hemisphere calibration, 0–50,000 years cal BP. Radiocarbon 55:1–15

Inda H, del Puerto L (2002) Identificación taxonómica de muestras de material leñoso. Informe inédito. FC, 1–8 pp

Iriondo M, Kröhling D (2008) Cambios ambientales en la cuenca del Río Uruguay. Universidad Nacional del Litoral, Santa Fé

Jouzel J, Masson-Delmotte V, Cattani O, Dreyfus G, Falourd S, Hoffmann G, Minster B, Nouet J, Barnola JM, Chappellaz J, Fischer H, Gallet JC, Johnsen S, Leuenberger M, Loulergue L, Luethi D, Oerter H, Parrenin F, Raisbeck G, Raynaud D, Schilt A. Schwander J, Selmo E, Souchez R, Spahni R, Stauffer B, Steffensen JP, Stenni B, Stocker TF, Tison JL, Werner M, Wolff EW (2007) Orbital and millennial Antarctic climate variability over the past 800,000 years. Sci 317:793–796

Kerber L, Kinoshita A, José F, Graciano A, Oliveira E, Baffa O (2011) Electron spin resonance dating of the southern Brazilian pleistocene mammals from Touro Passo formation, and remarks on the geochronology, fauna and paleoenvironments. Quat Int 245:201–208

Long J, Stoy P (2013) Quantifying the periodicity of heinrich and dansgaard-oeschger events during marine oxygen isotope stage 3. Quat Res 79:413–423

Lopez J (2013) Early human occupation of Uruguay: radiocarbon database and archaeological implications. Quat Int 301:94–103

Lorenzo N (2009) Camélidos del Pleistoceno de Uruguay: análisis morfológico cualitativo y multivariado. Dissertation, PEDECIBA, Universidad de la República

Martínez S, Rojas A (2004) Quaternary continental mollusks from northern Uruguay: distribution and paleoecology. Quat Int 114:123–128

Martínez S, Ubilla M (2004). El Cuaternario en Uruguay. In: Veroslavsky G, Ubilla M, Martínez S (eds) Cuencas sedimentarias de Uruguay. Geología, Paleontología y Recursos Naturales. Cenozoico. DIRAC-FC, Montevideo

MEC (1989) Misión de Rescate Arqueológico de Salto Grande. Ministerio de Educación y Cultura. Montevideo 2–3:609

Morosi E, Ubilla M (2014) Preliminary report on isotopic studies ($\delta^{13}C$) in living and Late Pleistocene ungulates of Uruguay: paleoecological inferences. Abstracts 4th International Palaeontol Congress, p 757

Noriega J (1991) Un nuevo género de Furnariidae (Aves, Passeriformes) del Pleistoceno inferior-medio de la provincia de Buenos Aires, Argentina. Ameghiniana 28:317–323

Orombelli G, Maggi V, Delmonte B (2010) Quaternary stratigraphy and ice cores. Quat Int 219:55–65

Paisani JC, Pontelli ME, Osterrieth M, Lopes S, Fachin A, Guerra S, Olivera L (2014) Paleosols in low-order streams and valleys heads in the Araucaria Plateau—record of continental environmental conditions in southern Brazil at the end of MIS 3. J S Am Earth Sci 54:57–70

Panario D, Gutiérrez O (1999) The continental Uruguayan Cenozoic: an overview. Quat Int 62: 75–84

Panario D, Gutiérrez O, Sánchez L, Peel E, Oyantcabal P, Rabassa J (2014) Ancient landscapes of Uruguay. In: Rabassa J, Olliers C (eds) Gondwana landscapes in Southern South America. Springer Earth System Science, Springer, Berlin

Perea D (2008) *Nothrotherium* cf. *N. maquinense* (Xenarthra, Tardigrada) en la Formación Sopas (Pleistoceno Tardío de Uruguay). Rev Soc Uruguaya de Geología 14:2–6

Porpino K, Fernicola J, Bergqvist L (2010) Revisiting the intertropical brazilian species *Hoplophorus euphractus* (Cingulata, Glyptodontoidea) and the phylogenetic affinities of *Hoplophorus*. J Vertebr Paleontol 30:911–927

Prevosti F, Ubilla M, Perea D (2009) Large extinct canids from the Pleistocene of Uruguay: systematic, biogeographic and palaeoecological remarks. Hist Biol 21:79–89

Prosul (2009–2011) Estudo integrado do Cuaternario da Regiao Oeste do Rio Grande do Sul, Regiáo Mesopotamica e pampeana da Argentina e Noroeste do Uruguai". CNPq-Prosul 490299/2008-3. Coordenador: Dr. Ana Ribeiro (FZB)

Rabassa J, Ponce J (2013) The Heinrich and Dansgaard-Oeschger climatic events during Marine Isotopic Stage 3: searching for appropriate times for human colonization of the Americas. Quat Int 299:94–105

Ribeiro A, Scherer C (2009) Mamíferos do Pleistoceno do Rio Grande do Sul, Brasil. In: Ribeiro, Girardi, Saldanha (eds) Quaternario de Rio Grande do Sul. Integrando Conhecimentos. Monografías Sociedade Brasileira de Paleontología, Porto Alegre

Scherer C (2009) Os Camelidae Lamini (Mammalia, Artiodactyla) do Pleistoceno da America do Sul: aspectos taxonómicos e filogenéticos. Dissertation, UFGRS-IG-Pgraduacao

Stuiver M, Reimer P, Reimerl R (2103) CALIB radiocarbon calibration. http://calib.qub.ac.uk/calib/

Suárez R (2011) Arqueología durante la Transición Pleistoceno Holoceno en Uruguay: Componentes Paleoindios, organización de la tecnología lítica y movilidad de los Primeros

Americanos. Archaeopress, British Archaeological Reports (BAR) International Series 2220, Oxford

Suárez R, López J (2003) Archaeology of the Pleistocene-Holocene transition in Uruguay: an overview. Quat Int 109:65–76

Suárez R, Santos G (2010) Cazadores-recolectores tempranos, supervivencia de fauna del Pleistoceno (*Equus* y *Glyptodon*), y tecnología lítica durante el Holoceno temprano en la frontera Uruguay-Brasil. Revista de Arqueología 23:20–39

Tambussi C, Ubilla M, Acosta Hospitaleche C, Perea D (2005) Fossil records and palaeoenvironmental implications of *Chloephaga picta* (Gmelin, 1789) (Magellan Goose) and *Cariama cristata* (Linnaeus, 1766) (Seriema) from the Late Pleistocene of Uruguay. Neues Jarb Geol und Palaeontol Mh 5:257–268

Tambussi C, Acosta Hospitaleche C, Rinderknecht A, Ubilla M (2009) Parrots (Aves, Psittaciformes) in the Pleistocene of Uruguay. Ameghiniana 46:431–435

Toledo M (2011) El legado lujanense de Ameghino: revisión estratigráfica de los depósitos pleistocenos-holocenos del Valle del Río Luján en su sección tipo. Registro paleoclimático en la pampa de los estadios OIS 4 al OIS 1. Rev Asoc Geol Argentina 68:121–167

Tonni EP, Carbonari J, Huarte R (2010) Marine sediments attributed to Marine Isotope Stage 3 in the southeastern buenos aires province, Argentina. Curr Res Pleistocene 27:154–156

Ubilla M (2001) Comment on "The continental Uruguayan Cenozoic: an overview" by D. Panario and O. Gutiérrez (Quaternary International 62:75–84). Quatern Int 76–77:259–260

Ubilla M (2004) Mammalian biostratigraphy of Pleistocene fluvial deposits in northern Uruguay, South America. Proc Geologists' Assoc Lond 115:347–357

Ubilla M (2008) Postcranial morphology of the extinct caviine rodent *Microcavia criolloensis* (late Pleistocene, South America). Zoological J Linn Soc 154(4):780–806

Ubilla M, Perea D (1999) Quaternary vertebrates of Uruguay: biostratigraphic, biogeographic and climatic overview. Quat S Am Antarctic Pen 12:75–90

Ubilla M, Piñeiro G, Quintana C (1999) A new extinct species of the genus *Microcavia* (Rodentia, Caviidae) from the upper pleistocene of the northern basin of Uruguay (South America) with paleobiogeographic and paleoenvironmental comments. Stud Neotrop Fauna Environ 34: 141–149

Ubilla M, Perea D, Goso C, Lorenzo N (2004) Late Pleistocene vertebrates from northern Uruguay: tools for biostratigraphic, climatic and environmental reconstruction. Quat Int 114:129–142

Ubilla M, Perea D, Rinderknecht A, Corona A (2009) Pleistocene mammals from Uruguay: biostratigraphic, biogeographic and environmental connotations. In: Girardi S, Scherer C (eds) Ribeiro AM. Quaternario de Rio Grande do Sul. Integrando Conhecimentos. Monografías Sociedade Brasileira de Paleontología, Porto Alegre

Ubilla M, Perea D, Bond M, Rinderknecht A (2011) The first cranial remains of the Pleistocene Proterotheriid *Neolicaphrium* Frenguelli, 1921 (Mammalia, Litopterna): a comparative approach. J Vertebr Paleontol 31(1):193–201

Van Meerbeeck CJ, Renssen H, Roche DM (2009) How did Marine Isotope Stage 3 and last glacial maximum climates differ? Perspectives from equilibrium simulations. Clim Past 5: 33–51

Van Meerbeeck CJ, Renssen H, Roche DM, Wohlfarth B, Bohncke SJ, Bos J, Engels S, Helmens K, Sánchez-Goñi M, Svensson A, Vandenberghe J (2011) The nature of MIS 3 stadial-interstadial transitions in Europe: new insights from model-data comparisons. Quat Sci Rev 30:3618–3637

Verde M, Ubilla M (2002) Mammalian carnivore coprolites from the Sopas Formation (Upper Pleistocene, Lujanian Stage), Uruguay. Ichnos 9:77–80

Verde M, Ubilla M, Jiménez J, Genise J (2007) A new earthworm trace fossil from palaeosols: aestivation chambers from the late pleistocene Sopas Formation of Uruguay. Palaeogeogr Palaeoclimatol Palaeoecol 243:339–347