Chapter 3
Continental Beds

Abstract The Continental Quaternary sedimentary beds of Uruguay yield useful information for helping to understand the environmental, climatic, and biotic evolution in this region of South America. Most of the units described have a rich paleontological content encompassing wood, fresh-water mollusks, pollen, trace-fossils, and a panoply of vertebrates, with mammals the dominant group (updated tables and selected material on them is included). Lithological units are analyzed in terms of their sedimentary features, the various estimations of their chronology, the depositional environment and fossil content, and its environmental and biogeographic connotation. Economic interest in the units is also brought to light. The Salto, Sopas and Dolores Formations have been selected for detailed discussion, and additional commentaries are provided about the Bellaco, Raigón and Libertad Formations. The sedimentary beds are representative of different time periods, including a fluvial braided system related to a proto Uruguay river in western Uruguay, fluvial contexts with channels and plain-flooded facies along with paleosoils in northern Uruguay, and transitional deposits in southern Uruguay. According to numerical ages, arranged in updated tables, correlation with the Marine Isotope Stage 3 (MIS-3) and MIS-2 is discussed for southern and northern Late Pleistocene beds. In this sense, evidence is analyzed that is based on the fossil content, implying that biogeographic processes—likely related to the climatic conditions—occurred during these time intervals.

Keywords Salto Formation · Sopas Formation · Dolores Formation · Geology · Paleontology · Paleoecology · Radiocarbon · OSL/TL · Trace-fossils

3.1 Geological Features

3.1.1 Salto Formation

According to Veroslavsky and Ubilla (2007), the Salto Formation is a member of the Salto depositional sequence. This sequence is located in northwestern Uruguay

M. Ubilla and S. Martínez, *Geology and Paleontology of the Quaternary of Uruguay*, SpringerBriefs in Earth System Sciences,
DOI 10.1007/978-3-319-29303-5_3

(Fig. 3.1) and includes braided river deposits, and lacustrine and probably aeolian deposits. The Salto depositional sequence is formed by two cycles (Fig. 3.2); the lower one is represented by most of the Salto Formation, and the upper one includes the uppermost levels of this unit and the gypsum clay bodies of the Bellaco Formation. Goso and Bossi (1966) described the "Areniscas de Salto" of Caorsi and Goñi (1958) as the Salto Formation, but the sediments of this unit were previously reported on by several authors (Frenguelli 1920; Walther 1931; Lambert 1940a, b among others). It crops out discontinuously in western Uruguay (Fig. 3.1), overlies Cretaceous and Late

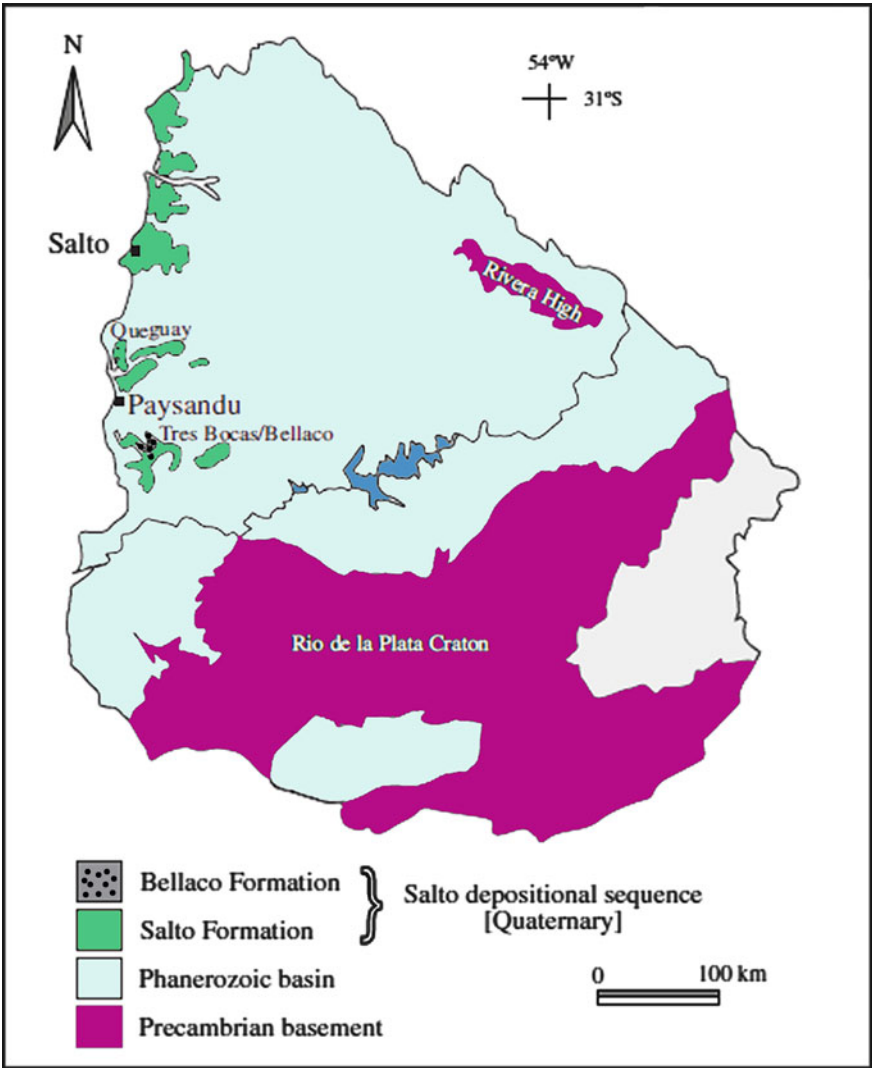

Fig. 3.1 Geographic location of the Salto Formation

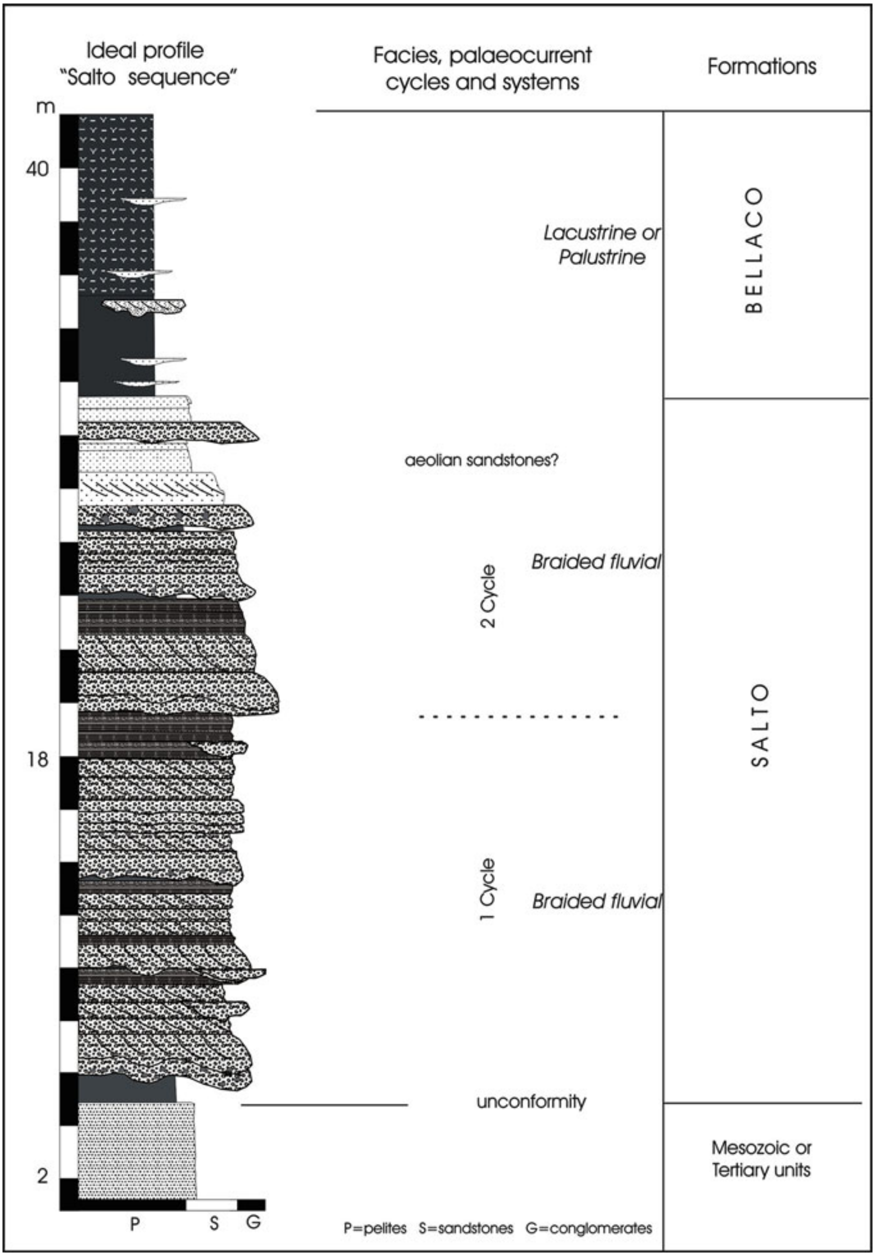

Fig. 3.2 Generalized stratigraphic profile of the Salto depositional sequence including the Salto and the Bellaco Formations (adapted from Veroslavsky and Ubilla 2007)

Paleogene strata, and underlies Pleistocene levels. It has economic value since it is used as an aquifer and is occasionally the substratum for citrus cultivation.

The Salto Formation is more than 35 m thick (including surface and subsurface profiles) and is mostly represented by tabular and lenticular coarse sandstone beds intercalated with sandy conglomerates and fine sandstones and pelites (see details in Veroslavsky and Ubilla 2007; Iriondo and Kröhling 2008) (Figs. 3.2 and 3.3). The lithological features of this unit reveal a sand-dominated braided system, with subordinate pelites and rare conglomerates. The sandstone facies yield trough-cross stratification predominantly on a medium to large scale, horizontal bedding, and massive sandstone; the sandstone includes armored mud balls and are mostly composed of quartz grain, feldspar, opal, and basalt and igneo-metamorphic fragments being the silica the dominant cement (Veroslavsky and Montaño 2004). Ferruginous sandy levels and strongly silicified beds are very common at the top of this unit. The pelites (massive and laminar) are mostly restricted to basal portions of the cycle and have mud cracks. The conglomerates are mostly massive.

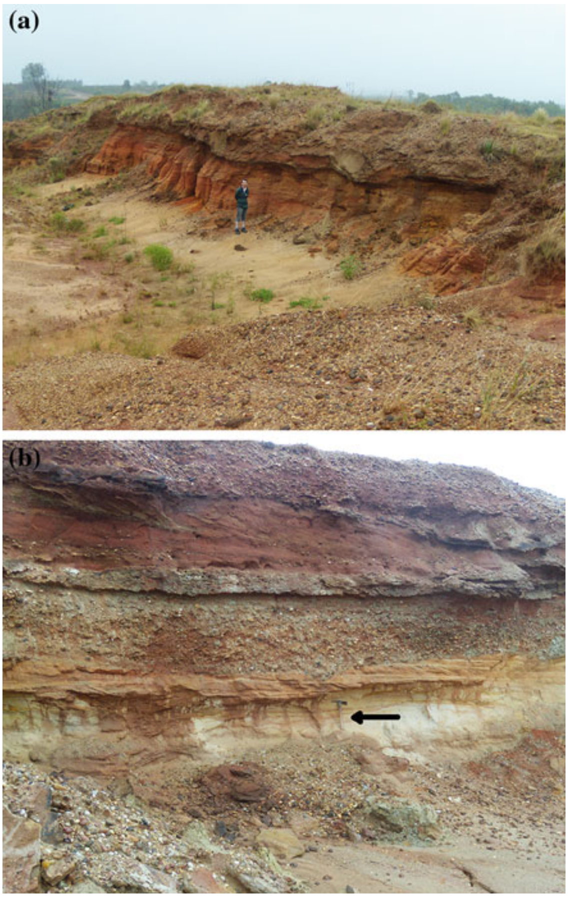

Fig. 3.3 **a** Beds of the Salto Formation, **b** coarse to fine sandy beds of the Salto Formation including horizontal and cross-stratification

3.1.2 Sopas Formation

This unit has a patched distribution at river, stream, and creek sides in northern Uruguay (mostly in the Artigas, Salto, Paysandú and Tacuarembó Departments), and usually crops out in a few hundred meters' length and up to 12–15 m in thickness (Fig. 3.4). Antón (1975) described two sedimentary units for northern

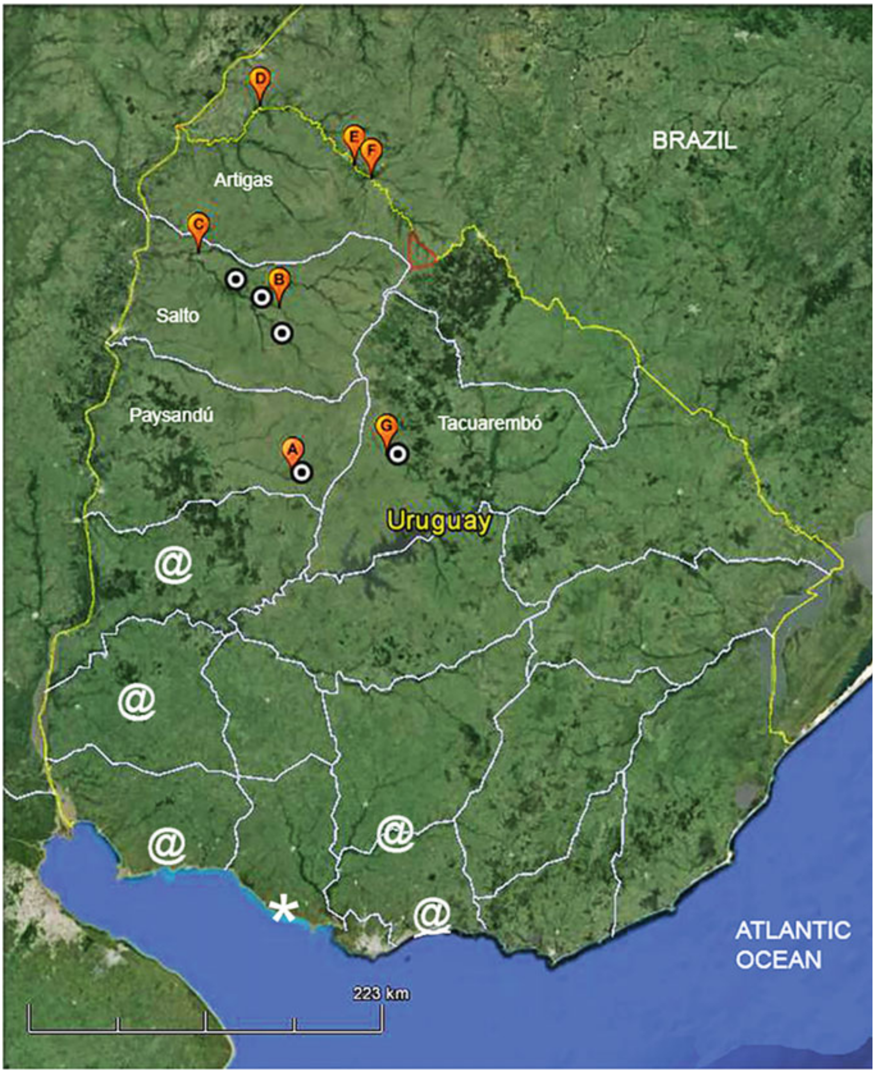

Fig. 3.4 **a–g** Geographic location of fossiliferous outcrops of the Sopas Formation. *White/black points* indicate geographic location of the ichnofossil *Castrichnus incolumis*, @ areas with outcrops of the Dolores Formation, * geographic location of the Raigón Formation

Uruguay: the Mataojo and Sopas Formations. He characterized the Sopas by massive brownish mudstones with disseminated gravel clasts and carbonates, including in the upper section layers of volcanic ash 30 cm thick. According to him, the Mataojo Formation consists of conglomerates with angular and rounded clasts usually located at the base of stratigraphic profiles. Panario and Gutiérrez (1999) classified the quaternary fluvial deposits of Uruguay as “upper terraces” and “lower terraces” and included the Dolores-Sopas Formation with two members into the lower ones. According to Ubilla and Perea (1999) and Ubilla et al. (2004), the conglomerates of the Mataojo Formation have scarce vertical and horizontal expression, a situation that makes it very difficult to map it so it always appears exposed in relation, and occasionally interbedded, with the brown mudstones of the Sopas Formation. Since it seems inappropriate to separate and define two different lithostratigraphic units, here the Sopas Formation includes those lithofacies that belong to the Mataojo and the Sopas Formation of Antón (1975) (Fig. 3.5). The sediments intermittently overlay Cretaceous basaltic rocks (the Arapey Formation) and Jurassic-Cretaceous aeolian sandstones (Tacuarembó Formation).

Based on several outcrops, Ubilla et al. (2004), and Goso Aguilar and Ubilla (2004) provided a lithofaciological characterization that is briefly synthesized here.

Fig. 3.5 **a**–**d** Outcrops of the Sopas Formation showing facies with conglomerates, sand, and mudstones

From the base to the top, the following fining-upwards pattern predominates in sections up to 12 m high (Fig. 3.5):

- Conglomerate with mud matrix (paraconglomerate), reddish and brown color, with pebble- to cobble-size clasts. The composition is basaltic, quartz, aeolian sandstone and chalcedony, both well-rounded and angularly round, although cross-stratification is very common with irregular base contact and channelized geometries that are exposed. The sets are 0.40–1.50 m thick and they can have a rich content of vertebrate and mollusk fossils remains.
- Thin and coarse to fine sandstones with a silt matrix a few centimeters thick, showing ripple and normal graded lamination interbedded with the previous lithology.
- Mudstones and brownish-colored wackestones. Intercalated gravel clasts forming thin bed-sets 3–4 cm thick are also present. This facies yields vertebrates, bivalves, gastropods, and ichnofossils. The wackestone facies exhibit predominantly traction structures. The presence of levels with carbonate concretions, dust and duricrusts that appear mainly at the top of the sections along with rhizo-concretions are very often found.

3.1.3 Dolores Formation

This sedimentary unit described by Goso (1972) is mostly seen in southern Uruguay (the Soriano, Río Negro, Colonia, and Canelones Departments, among others) (Fig. 3.4) with up to 10 m thick outcrops. It overlays the Chuy Formation (Pleistocene), the Fray Bentos Formation (Oligocene) and Precambrian rocks (Preciozzi et al. 1985; Martínez and Ubilla 2004). Beds of the Dolores Formation are studied on coastal cliffs (Canelones and Colonia Departments), rivers, and creek banks (Spoturno et al. 2004; Goso Aguilar 2006). It is characterized by brownish to green/gray siltstones, pelites, and sandy to gravelly pelites and sandstones, with an argillaceous matrix (Preciozzi et al. 1985; Bossi and Navarro 1991) (Fig. 3.6). Carbonate, massive silty-clay sediments, parallel lamination, incised lobes, and tabular deposition were also described (Goso Aguilar 2006). The newest soils of southern Uruguay have been developed from this unit. It is different from the Libertad Formation due to some of its geomorphological features (Martínez and Ubilla 2004).

3.1.4 Other Units

The Raigón Formation, described by Goso and Bossi (1966) (similar to the San José Formation of Francis and Mones 1965), outcrops in southwestern Uruguay's coastal cliffs of 5 m thick on the surface, but up to 50 m in the subsurface (Fig. 3.4).

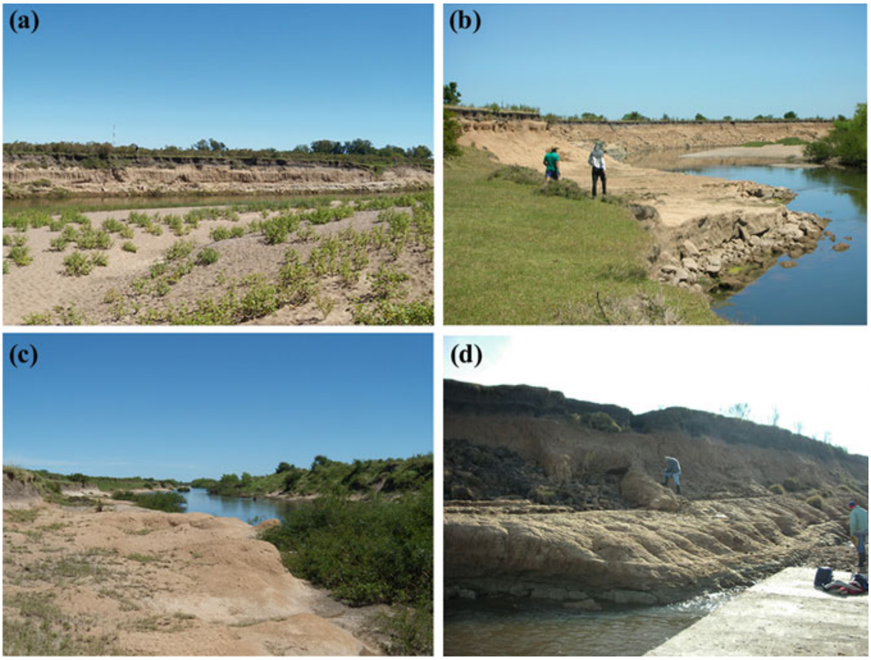

Fig. 3.6 **a–d** Outcrops of the Dolores Formation at the Santa Lucía Basin (southern Uruguay)

It is mostly characterized by fining upward to coarse sandy levels, including parallel and cross-bedding stratification, with intercalated massive silty-clayey greenish beds (Fig. 3.7) (Perea and Martínez 2004; Tófalo et al. 2009). Bossi et al. (2009) described two members of this unit, from the base to the top—the San José Member and the San Bautista Member. According to these authors, sandstones and conglomerates, along with fine clayish sandstones, dominate the first; the second is represented by loess that constitutes paleosoil evolution. Similar to the Salto strata, the Raigón sedimentary bed is also an important aquifer strongly related to agro-industrial activities.

Goso and Bossi (1966) described the Libertad Formation in southern Uruguay which, according to Preciozzi et al. (1985), is up to 30 m high (with the surface and subsurface). It lies unconformable on Paleozoic and tertiary rocks and under Late Quaternary beds or recent soils (Tófalo et al. 2009). It is mainly characterized by brown mudstones with scattered coarse sand, loess and calcium carbonate. Paleosoils, tabular geometry and coarse stratification were observed, but the absence of internal sedimentary structures dominates (Bossi et al. 2009; Tófalo et al. 2009). Geomorphological studies envisage at least two depositional episodes (Libertad I and Libertad II) related to climatic changes (Panario and Gutiérrez 1999). This unit was also interpreted as the result of the weathering of various types of rocks, especially those of the San Bautista member of the Raigon Formation (Bossi et al. 2009).

Fig. 3.7 **a**–**b** Outcrops of the Raigon Formation (*arrow* indicates upper limit), **c** cross-stratification in the Raigón Formation

3.2 Numerical Ages

3.2.1 Salto Formation

There are various opinions on the age of the Salto Formation; they are mostly based on stratigraphic evidence or correlation with climatic processes. Stratigraphic

Table 3.1 Thermoluminescence (TL) and Optically Stimulated Luminescence (OSL) ages of the Salto and the Raigón Formations

ID lab Formation	S	Sample location	TL/OSL Age (yr)
SALTO Formation			
–	Fs	Near Salto	88,370 ± 35,680
LVD-948	Fs	Salto City	986,000 ± 100,000
LVD-949	Fs	Salto dep.	830,000 ± 95,000
RAIGÓN Formation			
LVD-1450	Ms	Arazati, SJ	218,000 ± 26,000
LVD-1451	Ms	Ordeig, SJ	100,000 ± 12,000
UIC-3457	Fs	Ordeig, SJ	373,765 ± 28,455**
UIC-3334	Fs	Ordeig, SJ	>180,000**
UIC-3335	Ms	Arazatí, SJ	>390,000**
UIC-3337	Cs	Arazatí, SJ	>222,000**
UIC-3456	Ms	Arazatí, SJ.	>230,000**
UIC-3452	Fs	Arazati, SJ	>154,000**

Iriondo and Kröhling (2003), Veroslavsky and Ubilla (2007), Ubilla et al. (2009), **this paper
S sample, *Fs* fine sand, *Ms* medium sand, *Cs* coarse sand, *SJ* San José

relationships, as previously mentioned, indicate an age not older than the Late Oligocene and not younger than the Late Pleistocene. This unit was considered Late Miocene, Pliocene, and Pleistocene by various authors (see details in Table 2 in Veroslavsky and Ubilla 2007; Panario et al. 2014). There are numerical ages based on Optically Stimulated Luminescence and Thermoluminescence (OSL/TL) methods that reinforce the estimation of a Pleistocene age suggested by a few authors (see Goso 1972; Antón 1975; Goso and Bossi 1966). Two ages were proposed that were based on sandy friable samples from two localities taken from levels of the lower cycle of the Salto sequence (Veroslavsky and Ubilla 2007): 986 ± 100 ky and 830 ± 95 ky (Table 3.1). In this sense, an Early-Middle Pleistocene age is likely to be presumed. In addition, a TL age of 88.370 ± 35.680 years is assumed from the upper portion of the unit (Salto Department), related to the Late Pleistocene (Iriondo and Kröhling 2008).

3.2.2 Sopas Formation

According to the paleontological content (vide infra), a Late Pleistocene age was proposed for this unit, and a biostratigraphic correlation with the Lujanian stage/age (Late Pleistocene/Early Holocene) of the Buenos Aires Province was also postulated (Ubilla and Perea 1999; Ubilla et al. 2004). In the last few years, the number of numerical ages available for this unit successfully increased (Tables 3.2 and 3.3). Several conventional and AMS radiocarbon and OSL/TL ages were produced from different outcrops using samples of wood, fresh-water mollusk shells, mammal

Table 3.2 ^{14}C conventional and AMS ages from the Sopas Formation

ID Lab.	Taxon sample	M	Sample location	^{14}C age BP (Cal BP***)
LP-594	Wood indet	Wood	RCA	12,100 ± 140 (13,550–14,373)
AA104912*	*Cyanocyclas* sp.	Shell	TARN	12,502 ± 55 (14,234–15,001)**
AA99843*	Wood indet	Wood	RCA	13,869 ± 54 (16,473–16,983)**
AA104915*	*Pomacea* sp.	Shell	MT	33,560 ± 700 (36,089–39,426)**
AA101329*	*Pomacea* sp.	Shell	MT	35,530 ± 680 (38,659–41,421)**
AA104914*	*Pomacea* sp.	Shell	MT	37,070 ± 810 (39,940–42,665)**
AA104913*	*Pomacea* sp.	Shell	MT	38,300 ± 940 (40,865–43,932)**
AA104911*	*Cyanocyclas* sp.	Shell	MT	39,900 ± 1,100 (42,025–45,389)**
AA101328*	*Diplodon* sp.	Shell	MT	>45,200**
URU-0032	*D. peraeformis*	Shell	MT	>45,000
URU-0031	*D. peraeformis*	Shell	MT	>45,000
URU-0053	*Prosopis nigra*	Wood	CSS	>45,000
LP-490	*Prosopis* sp.	Wood	RCA	>43,000
URU-0036	*Prosopis* sp.	Wood	RCA	>45,000

Ubilla and Perea (1999), Ubilla et al. (2004), **Ubilla et al. accepted (2015)
*AMS ones
***95.4 (2 sigma), *M* material, *RCA* Río Cuareim (Artigas), *TARN* Tres Arboles creek (Río Negro), *MT* Malo creek, (Tacuarembó), *CSS* Cañada Sarandí (Salto)

bones and teeth, and sediment. Unfortunately, bones and teeth provided little information (Ubilla 2001; Martínez and Ubilla 2004).

Some radiocarbon ages are interpreted as minimum ages, but many finite ages were also produced (Table 3.2). A set of radiocarbon ages range from 33,560 ± 700 yrs BP (cal 36,089–39,426 yrs) to 39,900 ± 1,100 (cal 42,025–45,389 yrs), which correlate with the MIS-3. There are some outcrops with radiocarbon ages ranging from 12,100 ± 140 yrs. BP (cal 13,550–14,373 yrs) to 13,869 ± 54 yrs. BP (cal 16,473–16,983 yrs) that belong to younger facies of this unit. In any case, these ages corroborate the Late Pleistocene age of the unit based on the paleontological content.

A set of OSL/TL ages was produced from samples taken mostly from fossiliferous outcrops (Table 3.3) (Ubilla et al. accepted 2015). In particular, those ranging from 27,400 ± 3,300 to 71,400 ± 11,000 yrs also support a relationship with the Marine Isotope Stage 3 (MIS-3). Most ages fall in the 50–25 ka time interval and it is more frequently represented by the 45–28 ka time interval. Some of the older ages proposed should be taken with warning, because some have stratigraphic inversion or totally divert from this general pattern, becoming harder to explain.

Table 3.3 Optically Stimulated Luminescence (OSL) and Thermoluminescence (TL) ages of the Sopas Formation

ID Lab	S	Sample location	OSL/TL Age (yr)
UIC-3455	ms	ACr, Salto	14,485 ± 1,240**
LVD-1449	ms	Cr, Artigas	27,400 ± 3,300**
LVD-2657	Ss	Cr, Artigas	30,300 ± 3,700***
LVD-2660	sS	Sc, Salto	30,600 ± 5,400***
UIC-3458	ms	Mc, Tacuarembó	32,850 ± 1,990**
UIC-3451	ms	Mc, Tacuarembó	32,995 ± 1,930**
UIC-3332	ms	Mc, Tacuarembó	34,405 ± 2,240**
LVD-2655	Ss	Cr, Artigas	36,100 ± 6,200***
LVD-2661	ms	ACr, Salto	36,900 ± 6,500***
LVD-647	sSC	Sc, Salto	43,500 ± 3,600
LVD-646	sS	Mc, Tacuarembó	58,300 ± 7,400
LVD-2658	Ss	Cr, Artigas	71,400 ± 11,000***
LVD-1241	ms	Cr, Artigas	96,000 ± 11,000**
LVD-859	sS	Cr, Artigas	180,000 ± 20,000
LVD-857	s	Mc, Tacuarembó	200,000 ± 25,000
LVD-2659	Ss	Cr, Artigas	248,000 ± 26,000***
LVD-1242	sS	Mc, Tacuarembó	314,000 ± 39,300**
LVD-858	fs	Cr, Artigas	360,000 ± 40,000

Ubilla (2004), Ubilla et al. (2004), Martínez and Ubilla (2004), ***Prosul (2009–2011), **Ubilla et al. accepted (2015)

S sample, *ms* medium sand, *Ss* silty sand, *sS* sandy silt, *SsC* sandy silt crotovina, *s* silt, *fs* fine sand, *ACr* Arapey Chico River, *Cr* Cuareim River, *Sc* Sopas Creek, *Mc* Malo Creek

3.2.3 Dolores Formation

In the last few years, many numerical ages based on radiocarbon and OSL/TL methods were produced (the Rio Negro Department and several outcrops of the Santa Lucía Basin in southern Uruguay). According to this information, the last 30–10 ky lapse of time is represented (Tables 3.4 and 3.5). A set of radiocarbon ages based on organic soil, wood, and mammal teeth ranges from ^{14}C age of 22,450 ± 400 yrs BP (cal BP 25,934–27,436) to 10,140 ± 50 yrs BP (cal BP 11,857–11,960) (Table 3.4). The OSL/TL methods produced ages of 32,230 ± 2,640 yrs to 10,570 ± 990 yrs (Santa Lucía River Basin) (Table 3.5), which are stratigraphically consistent with regard to radiocarbon ages.

In previous studies, the Dolores Formation was interpreted as a Late Pleistocene unit based mostly on stratigraphic relationships and mammalian content (Preciozzi et al. 1985; Ubilla and Perea 1999; Martínez and Ubilla 2004), but the numerical dating indicates a Late Pleistocene to Early Holocene age.

Table 3.4 ^{14}C conventional and AMS ages from the Dolores Formation

Lab ID	Taxón sample	Material	SL	^{14}C age BP (Cal BP age***)
Beta301006*	–	Organic soil	Vc	10,140 ± 50 (11,857–11,960)
LP-1110	*Salix humboldtiana*	wood	SLrPC	10,480 ± 105 (11,982–12,647)
LP1143	–	wood	SLrPP	10,500 ± 110 (11,992–12,656)
LP1268	*Prosopis* sp.	wood	Vc	11,090 ± 110 (12,722–13,090)
LP1283	–	wood	SLrB	11,150 ± 120 (12,725–13,169)
AA91726*	*Equus* sp.	enamel	Pc	21,530 ± 140 (25,525–26,037)**
AA99845*	Deer	enamel	Pc	22,450 ± 400 (25,934–27,436)

Ubilla (1999), Martínez and Ubilla (2004), Meneghin (2011), Ubilla and Rinderknecht (2014a), **this work
*AMS ones
SL sample location, ***2 Sigma, *Vc* Vejigas Creek, *SLrPC* Santa Lucía River (Paso Cuello), *SLrPP* Santa Lucía River (Paso Pache), *SLrB* Santa Lucía River (Barrancas), *Pc*: Pilatos Creek

Table 3.5 Optically Stimulated Luminescence (OSL) and Thermoluminescence (TL) ages of the Dolores Formation

ID Lab	S	Sample location	OSL/TL Age (yr)
UIC-3052	fs	Vc Canelones	10,570 ± 990
UIC-3040	ms	EChc Colonia	15,730 ± 925
UIC-3039	ss	ECac Colonia	16,070 ± 930
UIC-3053	fs	Pc Canelones	23,785 ± 2,990
UIC-2822	fs	Pc Canelones	30,855 ± 2,370
UIC-2826	fs	Ac Canelones	31,160 ± 2,285
UIC-3302	ss	Ac Canelones	32,230 ± 2,640

Ubilla et al. (2013), Corona et al. (2013), Ubilla and Rinderknecht (2014a)
S sample, *fs* fine sand, *ms* medium sand, *ss* silty sand, *Vc* Vejigas Creek, *EChc* El Chileno Creek, *ECac* El Caño Creek, *Pc* Pilatos Creek, *Ac* Aparicio Creek

3.2.4 Other Units

The Raigón Formation, usually consistent with the Salto Formation, has been considered a Pliocene unit, but there is some evidence from upper levels that suggest also a Pleistocene age. Several OSL ages were produced from medium and upper beds using sandy samples (Table 3.1). Most are minimum ages, but there is one finite age of 373,7 ± 28,4 ky, indicating Medium Pleistocene, along with an OSL age of 218 ± 26 ky and 100 ± 12 ky from upper beds of the latest Medium and

Late Pleistocene. Bossi et al. (2009) proposed a Late Pliocene to Middle Pleistocene age, and Tófalo et al. (2009) a Late Pliocene to Early Pleistocene.

In northern Uruguay (Cuareim and Uruguay Rivers), there are sedimentary beds that are particularly interesting for archaeological studies (MEC 1989; Castiñeira et al. 2010; Suárez 2011; López Mazz 2013). It must be noted that most of the authors did not mention the sedimentary context of the Sopas Formation, except for Castiñeira et al. (2010). A large number of ^{14}C ages were produced, ranging from approximately 11 to 8,5 ky BP (Suárez and Lopez 2003; Castiñeira et al. 2010; Suárez and Santos 2010; Suárez 2011; López Mazz 2013, and references therein) (Table 3.6). The mammals *Equus* sp. and *Glyptodon* sp. were reported in association with lithic material in a 9 ky BP level (Suárez and Santos 2010). A calibration of the 11,200 ± 500 year BP age (MEC 1989) provides a 2 sigma cal BP 11,600–14,176 yrs, a roughly similar age for the Sopas Formation at the Cuareim River in northern Uruguay (cal 13,550–14,373 yrs).

The Libertad Formation has been considered by stratigraphic relationships to be a Lower to Middle Pleistocene unit (Martínez and Ubilla 2004). Recently, its age was considered to be around 20 ky, based on U-Th in *Macrauchenia* (Cid et al. 2014) and 17 ky for *Stegomastodon* (Gutiérrez et al. 2005) of a bone-bed in southern Uruguay (see below). Several studies of southern and eastern Uruguay (mostly related to archaeological excavations) provided many radiocarbon ages from different localities, ranging from 30 to 3 ky (Table 3.7) (Meneghin 2004, 2006, 2015; López Mazz 2013; Fariña et al. 2013, among others).

Table 3.6 Selected ^{14}C conventional and AMS ages from archaeological sites in northern Uruguay

ID Lab.	Material	SL	^{14}C age BP	Cal BP
URU 0079	charcoal	UrS	4,020 ± 70	–
URU 248	charcoal	PPA	8,570 ± 150	9,370–9,680
S7n	charcoal	CD3NS	9,300 ± 150	8,719–8,326
Rt 1445	charcoal	PPA	9,890 ± 75	9,450–9,261
UCLAMS21641*	charcoal	PPA	9,585 ± 25	10,960 > 11,000
UCLAMS28692*	charcoal	PPNA	10,465 ± 30	10,579–10,285
Kn2531	charcoal	IdTS	10,429 ± 90	10,571–10,194
UCLAMS21631*	charcoal	PPA	10,930 ± 20	10,919–10,763
GIF4412	charcoal	Ida	11,200 ± 500	11,600–14,176

Guidón (1989), Hilbert (1991), Austral (1995), Castiñeira et al. (2010), Suárez and Santos (2010), López Mazz (2013), Suárez 2009 in López Mazz (2013)

*AMS ones

SL sample location, *UrS* Uruguay river (Salto), *PPA* Pay Paso (Artigas), *CD3 NS* CalpicaDO3N (Salto), *PPNA* Pay Paso Norte, *IdTS* Isla del Tigre (Salto), *Ida* Isla de Arriba

Table 3.7 Selected ^{14}C conventional and AMS ages from archaeological sites in southern and eastern Uruguay

ID Lab.	Material	Locality	^{14}C age BP	Cal BP
Beta286135*	charcoal	UM	2,900 ± 40	3,170–2,930
URU-0515	charcoal	LIR	7,100 ± 160	6,202–5,789
CURL6078*	charcoal	LIR	8,510 ± 40	7,583–7,543
Beta165076*	charcoal	UM	10,690 ± 60	12,620–12,960
Beta380727*	charcoal	UM	10,800 ± 30	12,725–12,695
Beta211938*	charcoal	UM	11,690 ± 80	13,430–14,020
Beta395639*	charcoal	UM	12,000 ± 40	13,835–13,735
URU-0496	Bone *Lestodon*	VcC	27,000 ± 450	29,696 ± 871
URU-0493	Bone *Lestodon*	VcC	30,100 ± 600	32,886 ± 1,446

Meneghin (2004, 2015), López Mazz et al. (2009), Fariña et al. (2013)
*AMS ones
UM Urupez (Maldonado), *LIR* Los Indios (Rocha), *VcC* Vizcaíno Creek (Canelones)

3.3 Paleontological Context

3.3.1 Salto Formation

The fossil content of the Salto Formation has been scarce until now. It is represented by the silicified wood of small to medium trees referred to as Leguminosae and Caesalpinoideae without chronological information (Aznárez 1945) (Fig. 3.8). In general, there are preserved fragments or large portions of trunks that are likely parautochthonus revealing local transport. However, they have been referred trunks in life position (Iriondo and Kröheling 2008). The presence of the gastropod *Eoborus berroi* in this unit (Klappenbach and Olazarri 1986) was afterwards rejected and interpreted as reworked material from an older unit (Martinez et al. 1997).

3.3.2 Sopas Formation

This is a very fossiliferous sedimentary unit that includes trace-fossils (coprolites, nests, and caves) and body fossils (wood, fresh-water mollusk shells, and vertebrates). This fossil assemblage provides useful information for interpreting the climatic and environmental conditions involved.

Trace-fossils are represented by some burrow-like structures. The likely trace-producer is the now-extinct rodent *Microcavia criolloensis* (Ubilla et al. 1999) that was found to be associated with the burrows (Ubilla 2008); there are also structures interpreted as large paleocaves (Sopas Creek) (Fig. 3.9). The coprolites (Cuareim River) are related to medium to large predators (Verde and Ubilla 2002), and a canid origin was proposed (Chimento and Rey 2008). In fact, the

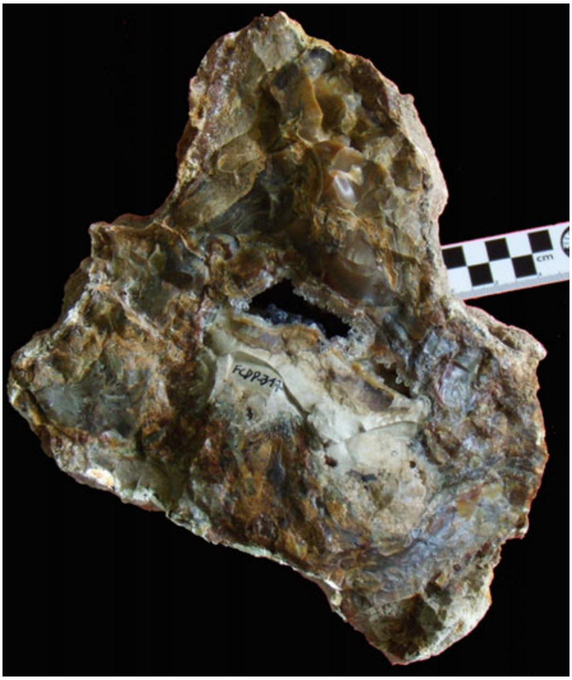

Fig. 3.8 Silicified wood of the Salto Formation

hypercarnivorous canids, such as *Protocyon* or *Dusicyon avus* (Prevosti et al. 2009) can be considered as possible producers. A very unique and abundant type of preservation is represented by *Castrichnus incolumis* and *Taenidium serpentinum* that were described by Verde et al. (2007) (Fig. 3.9), which was interpreted as earthworm estivation chambers produced in paleosoils (Sopas and Arerunguá Creeks, Salto; Malo Creek, Tacuarembó; Queguay River, Paysandú).

The wood remains provided limited information and some were determined to be *Prosopis* (Inda and del Puerto 2002; Ubilla et al. 2004; Martínez and Ubilla 2004) (Fig. 3.10). Fresh-water bivalves, gastropods, and a few terrestrial snails were described in several outcrops (Martínez and Rojas 2004). The bivalves are frequently found with articulated valves, and the gastropods are usually complete (Fig. 3.11).

The vertebrates of the Sopas Formation include a few Teleostei indet., reptiles, some birds, and numerous mammals (Tables 3.8 and 3.9) (Ubilla et al. 2004, 2011; Ubilla et al. accepted 2015). Large extinct terrestrial tortoises, the flightless bird *Rhea*, the seriema *Cariama*, and the Magellan-goose *Chloephaga* are among extant birds recorded in the Sopas Formation (Tambussi et al. 2005). Mammals are the dominant group (25 families in 9 orders, encompassing more than 50 species) and many extinct taxa and extinct species of extant genera are recorded. There are some taxa not represented in the present-day communities of Uruguay, but currently live in other areas of South America, such as some rodents, peccaries, and tapirs

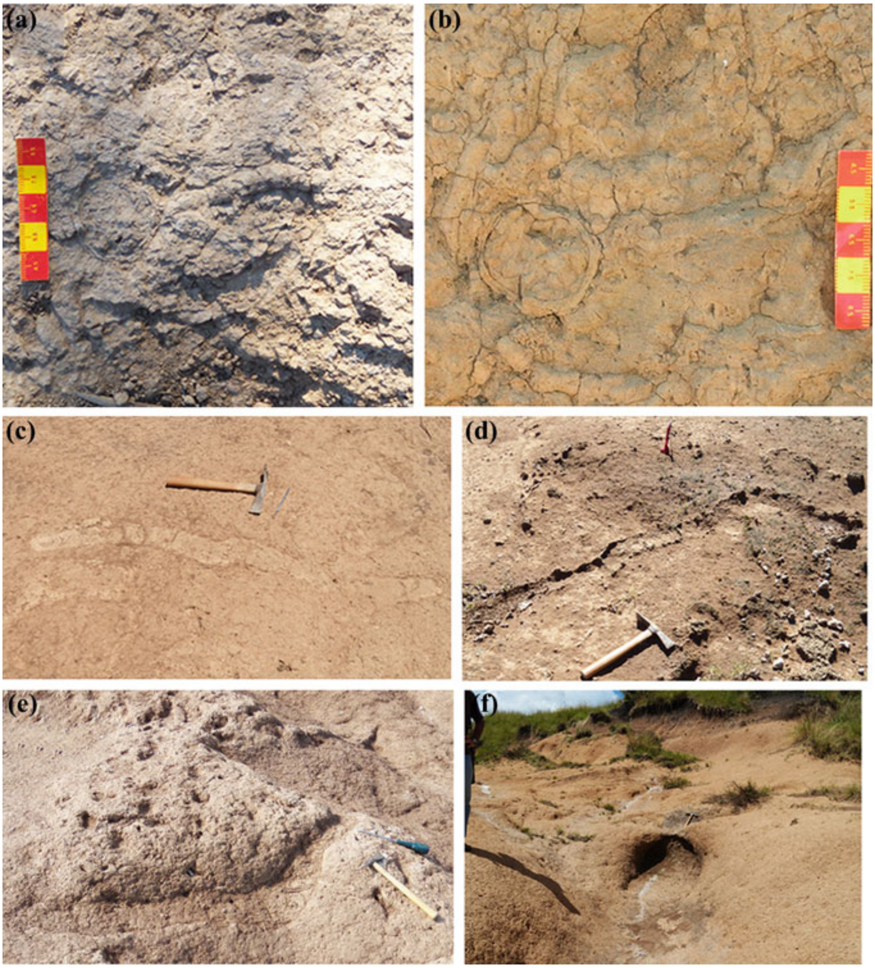

Fig. 3.9 **a**–**b** *Castrichnus incolumis* and *Taenidium serpentinum*, **c**–**e** rodent burrows, **f** paleocave

(Fig. 3.12). It shows local extinctions and shifting ranges. Ungulates (especially deer) and rodents are the groups most frequently represented in the fossil assemblage. Some very large to small herbivores, such as *Toxodon*, *Macrauchenia*, the horses *Equus neogaeus* and *Hippidion principale*, the ground sloth *Glossotherium, Neolicaphrium, Lama*, *Microcavia,* some omnivores, like the bear *Arctotherium* and large- to medium-sized predators like the jaguar *Panthera onca*, the mountain-lion *Puma*, and the extinct canid *Protocyon*, among others, were recorded (Table 3.9) (Fig. 3.13).

Fig. 3.10 **a**–**b** Wood remains of the Dolores Formation, **c** wood of the Sopas Formation

3.3.3 Dolores Formation

This unit yields pollen, a few fresh-water mollusks, a few turtles, and an important number of mammals that provide tools to understand environment and climatic conditions (Ubilla et al. 2009, 2011; De Oliveira et al. 2011; López Romanelli 2012). Preliminary pollen studies from facies of 11 to 10 ky reveal a dominance of

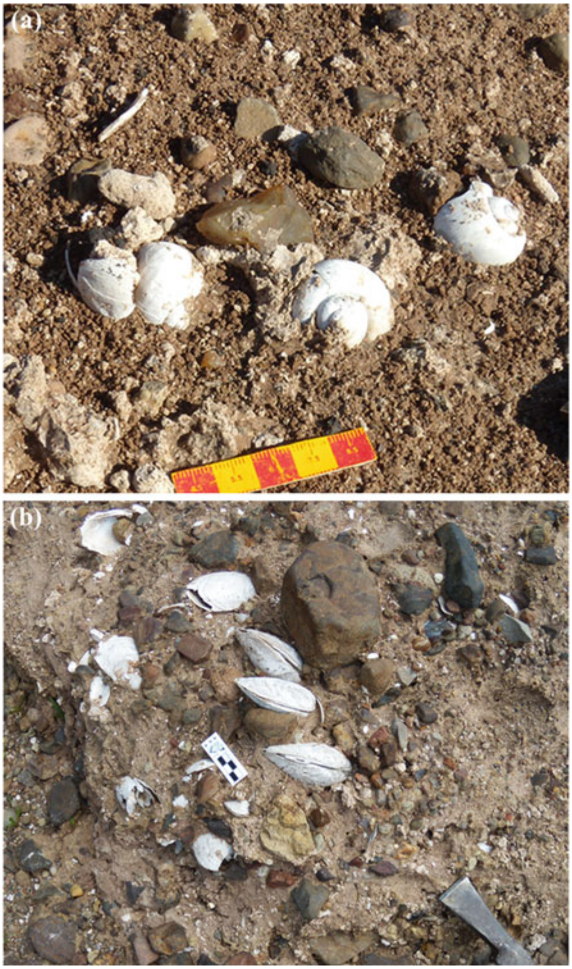

Fig. 3.11 **a** Gastropods (*Pomacea* sp.) of the Sopas Formation, **b** Articulated bivalves (*Diplodon* sp.) in the Sopas Formation

herbs, since trees and shrubs are scarce (De Oliveira et al. 2011). Typically extinct South American Pleistocene mammals are present; these include megafaunal representatives. *Macrauchenia patachonica*, *Toxodon* cf. *T. platensis*, the ground sloths *Glossotherium robustum* and *Catonyx cuvieri*, the glyptodonts *Glyptodon clavipes*, *Doedicurus clavicaudatus* and *Panochthus* cf. *P. tuberculatus*, armadillos as *Pampatherium typum*, the camelid *Hemiauchenia* sp., the horses *Equus neogeus* and *Hippidion* sp., gomphotheriid *Stegomastodon*, deer such as *Morenelaphus* sp., the sabre-tooth *Smilodon populator* and medium-size bear like *Arctotherium tarijense,* among others (Fig. 3.14). Some extinct large mammals (*Glyptodon*, *Morenelaphus,* large camelids) were recorded in beds with Early Holocene radiocarbonic ages. This information suggests that these kinds of animals could have survived until at least the early phases of Holocene at these latitudes.

Table 3.8 Updated list of non-mammal vertebrates for the Sopas Formation of northern Uruguay

Teleostei Paracanthopterygii/Acanthopterygii indet.
Testudines Family Testudinidae *Chelonoides sp.*
Squamata Family Teiidae *Tupinambis* cf. *T. teguixin*
Aves Family Rheidae *Rhea* sp. Brisson
Family Anatidae *Chloephaga picta*
Family Cariamidae *Cariama cristata*
Family Psitaciidae *Cyanoliseus patagonus*
Family Furnariidae cf. *Pseudoseisuropsis* sp.

Ubilla et al. (2004), Tambussi et al. (2005, 2009) and this work

Table 3.9 Updated list of mammals for the Sopas Formation of northern Uruguay

Order Didelphimorphia Family **Didelphidae** cf. *Didelphis* sp.	**Order Litopterna** Family **Macraucheniidae** *Macrauchenia patachonica* Family **Proterotheriidae** *Neolicaphrium recens* *N.* cf. *N. recens*
Order Xenarthra Family **Dasypodidae** *Dasypus* aff. *D. novemcinctus* *Propraopus* sp. Family **Pampatheriidae** *Pampatherium typum* *Pampatherium humboldti* Family **Glyptodontidae** *Glyptodon clavipes* cf. *Hoplophorus* *Neuryurus rudis* *Panochthus tuberculatus* Family **Megatheriidae** *Megatherium americanum* Family **Nothrotheriidae** *Nothrotherium* cf. *N. maquinense* Family **Mylodontidae** *Glossotherium robustum* *Lestodon armatus* *Catonyx cuvieri*	**Order Notoungulata** Family **Toxodontidae** *Toxodon* cf. *T. platensis* **Order Proboscidea** Family **Gomphotheriidae** indet. **Order Perissodactyla** Family **Tapiridae** *Tapirus terrestris* *Tapirus* sp. Family **Equidae** *Equus (Amerhippus) neogeus* *Hippidion principale*

(continued)

Table 3.9 (continued)

Order Carnivora Family **Canidae** *Lycalopex gymnocercus* *Dusicyon avus* *Protocyon troglodytes* Family **Felidae** *Felis concolor* *Panthera* cf. *P.onca* *Smilodon populator* Family **Mustelidae** *Lontra longicaudis* Family **Ursidae** *Arctotherium* aff. *A. bonariense*	**Order Artiodactyla** Family **Tayassuidae** *Tayassu pecari* *Catagonus* wagneri *Catagonus stenocephalus* Family **Cervidae** *Antifer ultra* *Ozotoceros* aff. *O. bezoarticus* *Morenelaphus brachyceros* *Morenelaphus lujanensis* *Paraceros fragilis* *Mazama* sp. Family **Camelidae** *Hemiauchenia paradoxa* *Lama guanicoe* *Palaeolama major* *Vicugna vicugna*
Order Rodentia Family **Cricetidae** *Reithrodon* sp. cf. *Wilfredomys oenax* *Lundomys molitor* Family **Erethizontidae** *Coendou magnus* Family **Echimyidae** *Myocastor coypus* Family **Chinchillidae** *Lagostomus* sp. Family **Caviidae** *Cavia* sp. *Galea* sp. *Microcavia criolloensis* *Dolichotis* sp. *Hydrochoerus hydrochaeris* *Neochoerus* cf. *N. aesopi*	

Ubilla et al. (2004, 2009, 2011) and references therein, Perea (2007), Prevosti et al. (2009), Scherer (2009), Gasparini et al. (2009, 2013), Corona et al. (2012), and this work

Also recorded are some mammals that are now extinct in this area but still extant in other regions of South America at the generic or specific level (the rodents *Microcavia*, *Galea, Dolichotis* cf. *D. patagonum*, *Lagostomus maximus*, the armadillo *Chaetophractus villosus*, the camelid *Vicugna* sp.*)* (Fig. 3.15) (Rego et al. 2007; Ubilla 2008; Ubilla et al. 2009, 2011; Corona et al. 2013; Ubilla and Rinderknecht 2014a, b). They illustrate shifting ranges or local extinctions. Most of the tropical to subtropical mammals found in the Sopas Formation (northern Uruguay) are absent.

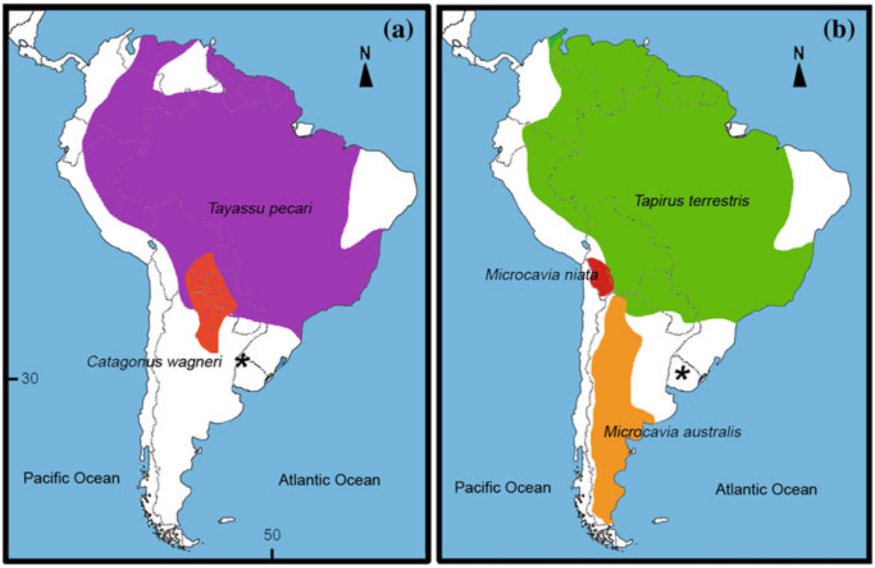

Fig. 3.12 **a** Current distribution of *Catagonus wagneri, Tayassu pecari* and their fossil record in Late Pleistocene of Uruguay (Sopas Formation), **b** Current distribution of *Tapirus terrestris*, *Microcavia* spp. and their fossil record in the Late Pleistocene of Uruguay (Sopas Formation). (Quintana 1996; Ubilla et al. 2004; Pardiñas and Ojeda 2008; Gasparini et al. 2013; Keuroghlian et al. 2013; Naveda et al. 2015)

3.3.4 Other Units

The Raigón Formation yields little yet interesting fossil content, mostly represented by vertebrates (Perea and Martínez 2004; Perea et al. 2013). Some ground-sloths and glyptodonts, toxodonts, large extinct phorusrhacids birds along with medium to giant rodents such as dinomyids (Tambussi et al. 1999; Rinderknecht and Blanco 2008; Perea et al. 2013) are among the most significant fossils (Fig. 3.16). Some mammals suggest a Pliocene to Medium Pleistocene age (Perea et al. 2013).

Probably belonging to the Libertad or Dolores Formation were some frogs that were described as *Ceratophrys* and *Leptodactylus*, a few birds, such as *Colaptes* and *Pseudosesiuropsis,* along with some extinct large mammals (Ubilla et al. 2011 and references therein). Many fossils were doubtfully assigned to the Libertad Formation (Ubilla and Perea 1999). However, a Late Pleistocene bone bed from southern Uruguay, including many taxa of vertebrates, dominated by mammals, is confidently referred to the Libertad Formation. Disarticulated and fractured bones are dominant in the assemblage that originated under a non-channelized mudflow. Glyptodonts, proboscideans, toxodonts, a large bear, and deer are the most representative taxa included in the bone bed (Corona et al. 2012).

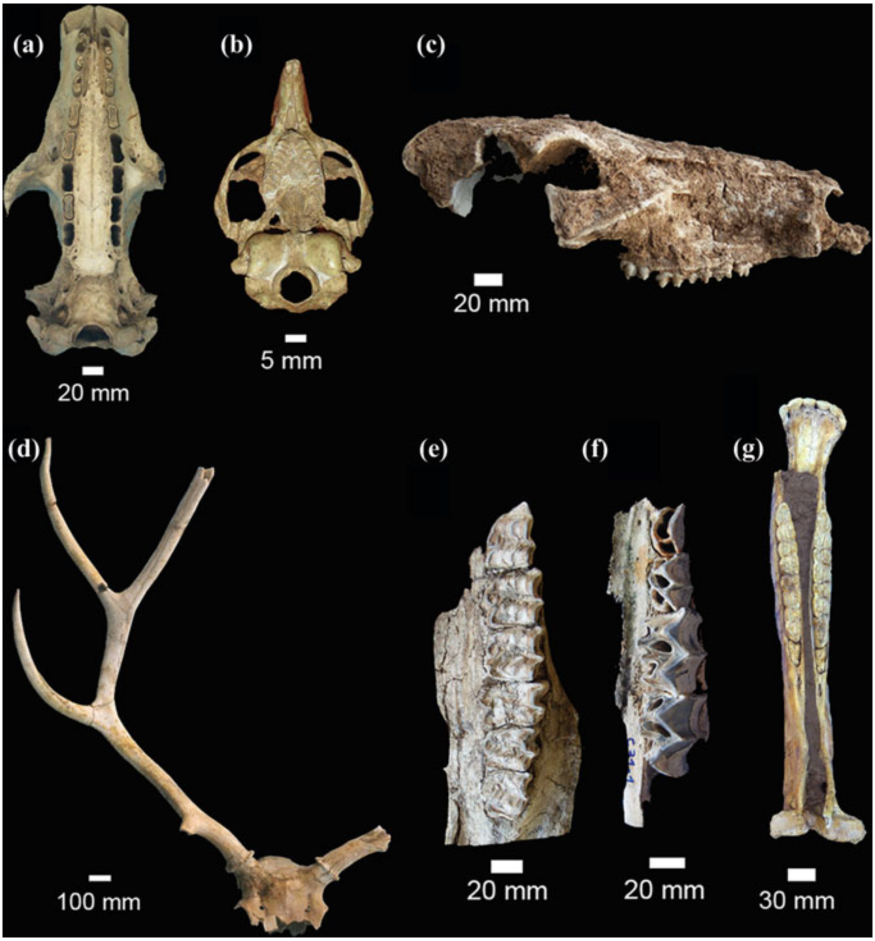

Fig. 3.13 Selected mammals of the Sopas Formation: **a** skull of the xenarthran *Pampatherium humboldti* (palatal view), **b** skull of the rodent *Microcavia criolloensis* (palatal view), **c** skull of the pecari *Catagonus wagneri* (lateral view), **d** skull and antler of the deer *Paraceros fragilis*, **e** upper dentition of the horse *Hippidion principale*, **f** upper dentition of the litoptern *Macrauchenia patachonica*, **g** mandibles of the horse *Equus neogeus*

There is another bone bed in southern Uruguay without reference to any sedimentary unit, including a variety of extinct giant mammals of 30 ky in age, where the ground-sloth *Lestodon* is predominant. Marks in some bones were interpreted as a result of human actions (Fariña et al. 2013), but the evidence is controversial (Suárez et al. 2014).

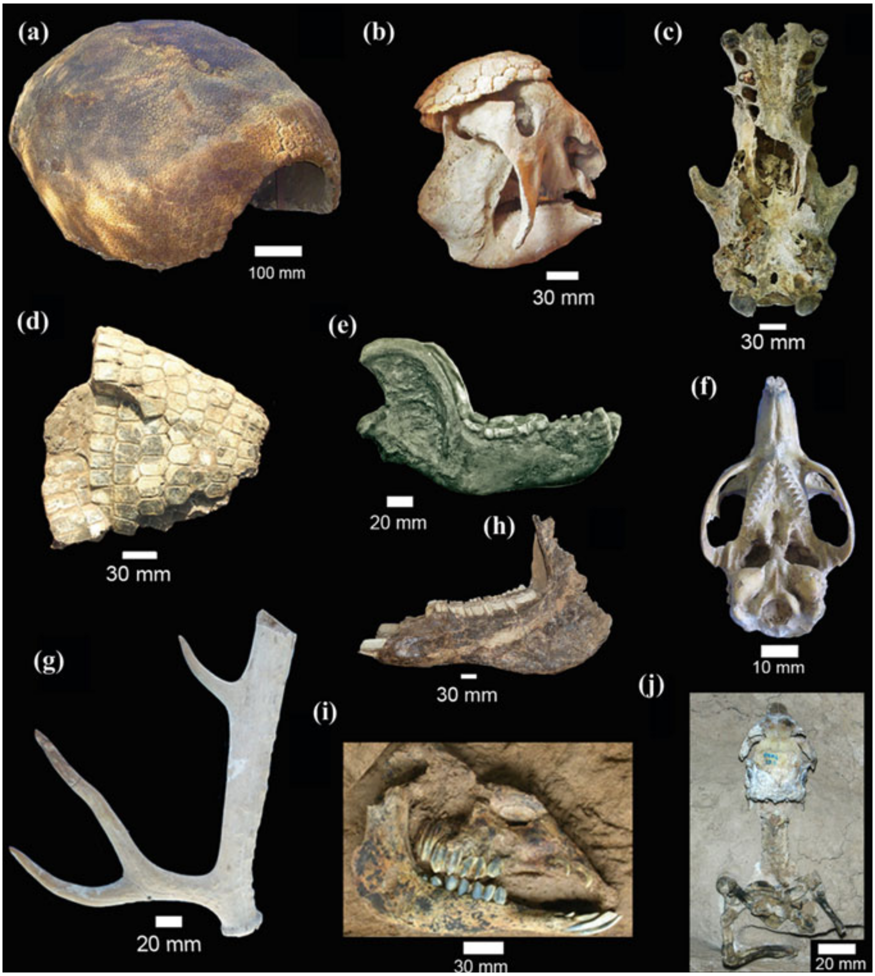

Fig. 3.14 Selected mammals of the Dolores Formation: **a** carapace of the glyptodont *Glyptodon clavipes*, **b** skull with dorsal shield (lateral view) of the glyptodont *Panochthus tuberculatus*, **c** skull (palatal view) of the ground sloth *Glossotherium robustum*, **d** anterior shoulder with fixed scutes of the xenarthran *Pampatherium typum,* **e** lateral view of the mandible of *Arctotherium tarijense*, **f** skull (palatal view) of the rodent *Galea ortodonta*, **g** antler of *Morenelaphus* sp., **h** mandibles of *Toxodon platensis*, **i** skull and mandible (lateral view) articulated of a juvenile of the camelid *Hemiauchenia*, **j** an almost complete and articulated skeleton of the rodent *Microcavia criolloensis*

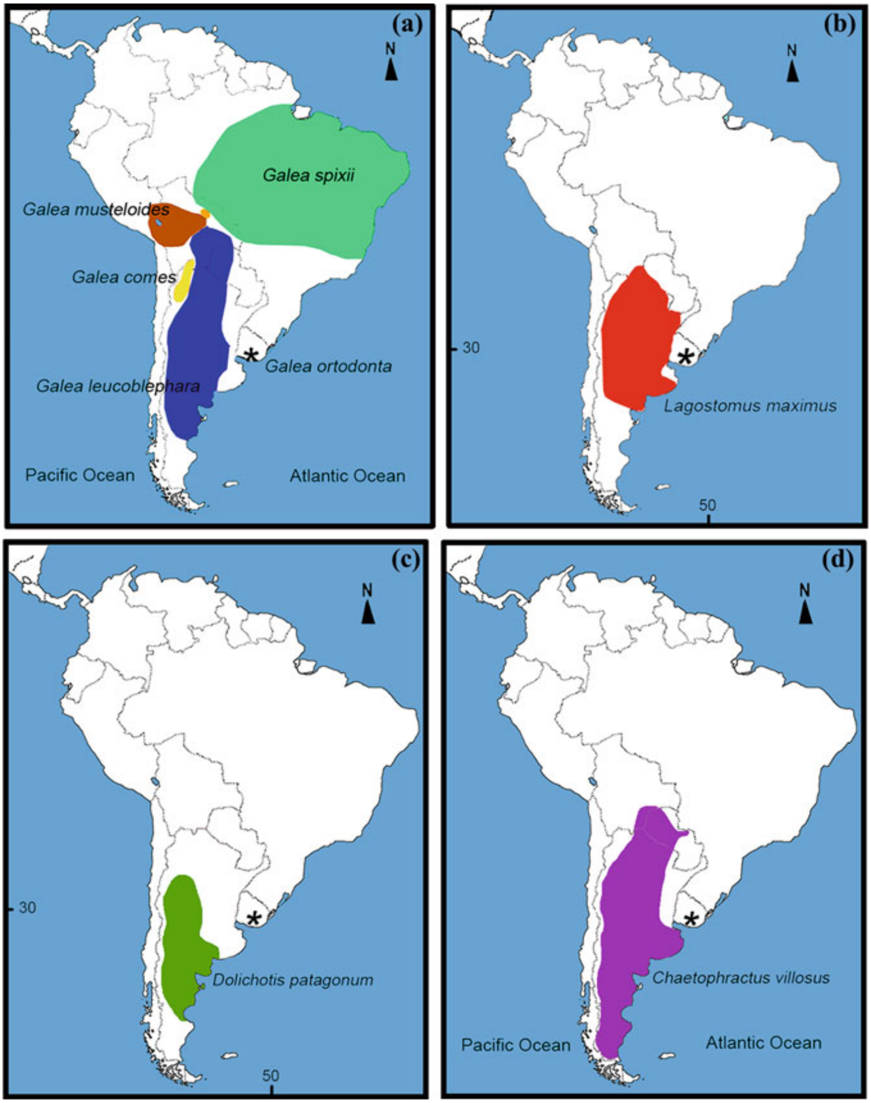

Fig. 3.15 **a** Current distribution of the rodent *Galea* spp. and the extinct *G. ortodonta* in Late Pleistocene of Uruguay (Dolores Formation), **b** current distribution of the rodent *Lagostomus maximus* and its record in the Late Pleistocene of Uruguay (Dolores Formation), **c** current distribution of the rodent *Dolichotis patagonum* and its record in the Late Pleistocene of Uruguay (Dolores Formation), **d** current distribution of *Chaetophractus villosus* and its Late Pleistocene record in Uruguay (Dolores Formation). (Abba et al. 2014; Ubilla and Rinderknecht 2014a, b; Patton et al. 2015)

Fig. 3.16 **a** Tibiotarsus of a large carnassial bird (Phorusrhacine) of the Raigón Formation compared with the extant large flightless bird *Rhea* sp. (**b**)

3.4 Environment and Climatic Scenarios

3.4.1 *Salto Formation*

According to the interpretation of the lithological features of the Salto Formation, the depositional environment was a fluvial braided system. It is considered to be related to a proto Uruguay River, actually a member of the Del Plata Basin (Veroslavsky and Ubilla 2007; Iriondo and Kröhling 2008; Panario et al. 2014). It primarily represents bedload deposits with low sinuosity and highly mobile broad and shallow channels. The armored mud balls well illustrate an erosive and auto-destructive behavior of the system. There is a tendency to assume that the Salto Formation was generated under arid or semi-arid climatic conditions (Bossi and Navarro 1991; Panario and Gutiérrez 1999); sedimentological, petrological and mineralogical information concur with this interpretation. In addition, if the gypsum clay beds of the Bellaco Formation are genetically associated with the Salto Formation, it strongly reinforces the evidence of an arid climate (Veroslavsky and Ubilla 2007). On the other hand, the OSL ages produced from the lower cycle indicate a correlation with some warm episodes of the Middle Pleistocene (Bradley 2015) such those corresponding to the OIS 25, 21, and 19.

Since both units, the Salto and the Bellaco Formations, today occupy high and low topographic locations in western Uruguay, there was invoked localized uplift by some authors (Bossi and Ferrando 2001 and references therein).

3.4.2 *Sopas Formation*

The sedimentary beds of this unit originated predominantly under fluvial contexts including channel and plain-flooded facies along with paleosoils observed in some localities (Ubilla et al. 2004; Goso Aguilar and Ubilla 2004). A variety of habitats can be assumed, based on the paleontological content (Ubilla et al. 2004). Fresh-water mollusks, the winter migratory bird *Chloephaga*, and some mammals (tapirs, marsh rice rats, capybaras, and river otters), represent lacustrine and fluvial environments. The avian and mammalian assemblage include taxa not only related to fluvial environment contexts, but also with open to semi-forested and forested areas (*Rhea*, *Cariama*, the horses *E. neogeus* and *H. principale*, the deer *Mazama*, and the rodent coendou, among others). A $\delta^{13}C$ isotope data for some ungulates (*Hippidion* cf. *H. principale*, *Equus neogeus*, deer, and a large camelid) indicate predominantly browser to mixed feeding habits likely related to semi-open environments (Morosi and Ubilla 2014). Some mammals (some rodents, peccaries, and camelids) also indicate arid to semi-arid environments, and the earthworm estivation chambers of *Castrichnus* are related to paleosoil development. According to the fossil content, the influence of the Last Interglacial or the Last Interstadial (MIS-3) was brought to mind (Ubilla et al. 2004). Extant representatives of mammalian taxa suggest a relationship with a benign climatic condition (inhabitants of tropical to temperate areas in South America). However, arid to semi-arid indicators were also found and are widespread today in mid- to high latitudes of South America. There is also evidence in favor of seasonality and perhaps droughts based on estivation chambers and winter migratory birds (Tambussi et al. 2005; Verde et al. 2007; Genise et al. 2013). These environmental and climatic conditions could have been developed by the influence of the MIS-3 climatic context that implied millennial climatic changes. The presence of tropical to subtropical taxa could be explained as survivors in environment refuges during the MIS-3 at this latitude due to the presence of perennial rivers, riparian forests and semi-forested areas (Ubilla et al. accepted 2015).

3.4.3 Dolores Formation

The sedimentary beds of this unit belong to continental environments (including gravity flows and reworked aeolian deposits) associated with a cold and arid to semi-arid climate (Martínez and Ubilla 2004; Goso Aguilar 2006). Open to semi-open environments and a predominance of grasslands are supported by pollen, extinct mammals as glyptodonts, and horses. Arid to semi-arid contexts are supported by some mammalian taxa like *Microcavia*, *Galea*, *Lama*, *Chaetophractus,* and *Lagostomus* among others, that today are extinct in Uruguay but live under such conditions in different regions of South America (Ubilla and Rinderknecht 2014a, b). Pollen from 10 to 11 ka beds indicates a dominance of herbs related to open areas accompanied by lotic contexts suggested by some aquatic weeds. According to the aforementioned numerical ages and the mammal record, the predominant climatic conditions were under the influence of the last phases of the MIS-3 and particularly the MIS-2, corresponding to the last glacial maximum. The predominance of a cold climate can explain the absence of tropical to subtropical mammals in the fossil assemblage.

3.4.4 Other Units

The Raigón Formation has a transitional to fluvial origin (Perea et al. 2013), presumably developed under a humid and seasonally climate (Tófalo et al. 2009) or arid to semi-arid conditions (Bossi et al. 2009; Panario et al. 2014). However, aeolian origin was also proposed for the top of the unit (Bossi et al. 2009). Several fossil vertebrates suggest open areas most likely related to semi-arid environments (Perea and Martínez 2004). If warm and arid conditions were prevalent, and according to the aforementioned OSL ages, correlation with some war episodes like MIS 11, 9 or MIS 7 and 5 is possible.

The consensus on environmental and climatic signals provided by the Libertad Formation is elusive. Semi-arid—including humid episodes—extremely rainy to glacial episodes, alternating episodes of dry and cold to warm and humid, are some of the available suggestions (Panario and Gutiérrez 1999; Bossi et al. 2009; Tófalo et al. 2009; Panario et al. 2014).

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