Quaternary International 751 (2026) 110047

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Freshwater invertebrate assemblages and environmental changes in the Late Pleistocene-Holocene of Salto de Piedra site (central Pampean Region, Buenos Aires, Argentina)

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ARTICLE INFO

Keywords:
Malacofauna
Paleoecology
Taphonomy
Climatic change
Late Pleistocene
Argentina

ABSTRACT

Salto de Piedra is a paleontological site located in the Buenos Aires Province (Argentina) close to Olavarría City at the upper basin of Tapalqué Creek. This site provides new insights about the late Quaternary climatic evolution of the area. The taxonomic and taphonomic analyses of freshwater gastropods from this period allow us to evaluate the magnitude of environmental changes in the area. Paleoclimatic inferences at the top of the sequence (Late Pleistocene) indicate a trend from arid conditions at facies 8 to humid ones towards facies 11 (Early Holocene). This transition from arid to humid conditions is also reinforced by post-depositional taphonomic processes. These bioindicators are analyzed with data on the geochemistry of the deposits containing them. Results indicate the alternation of palustrine and lacustrine conditions. These variations of local conditions are correlated with regional records of nearby archaeological sites that inferred arid to humid environmental transitions.

1. Introduction

Salto de Piedra locality (SPPL) is situated in the Interserrana area of de central Pampa (Fig. 1 (Favier Dubois et al., 2021). Research conducted at Salto de Piedra reveals an exceptional Middle–Late Pleistocene stratigraphic succession. Combined ESR, U-series, OSL, and AMS-^{14}C dating provide one of the oldest (~150 ka) and best-calibrated records of the last interglacial (MIS 5e) in the Argentine Pampas (Prado et al., 2024; Bellinzoni et al., 2025). The site preserves a thick sedimentary sequence containing a rich faunal assemblage with more than 25 mammalian taxa, including representatives of the Pampean megafauna as well as medium-sized species. The main groups identified comprise Xenarthrans (glyptodonts and ground sloths), native and exotic ungulates, camelids and cervids, and carnivores (Bellinzoni et al., 2024, 2025). The micromammal record includes rodents currently inhabiting the Humid Pampas, and also the Patagonian marsupial *Lestodelphys halli* and the semiaquatic sigmodontine *Holochilus brasiliensis* have been identified (Gómez et al., 2025). In addition, remains of species that became extinct during the Late Pleistocene (*Microcavia* cf. *M. robusta*) and the Holocene (*Galea tixiensis*) were recovered (Fernández et al., 2025). In summary, the co-occurrence of species adapted to contrasting environmental regimes (glyptodonts, equids, sloths, camelids) supports the hypothesis of an ecological transition between the Middle and Late Pleistocene, characterized by alternating humid and arid phases (Bellinzoni et al., 2025). These faunal changes are linked to broader climatic shifts during the Late Pleistocene-Holocene transition, including the Last Glacial Maximum (ca. 26–19 ka), the Antarctic Cold Reversal (ca. 14.7–13 ka), and the subsequent establishment of more humid Holocene conditions (Tonello and Prieto, 2010).

Despite the rich paleontological record at SPPL, no direct archaeological evidence—such as human remains, lithic industries, or clear anthropogenic modifications on bones—has been identified at the site. This absence is significant, as it provides a paleoenvironmental baseline representing conditions prior to or independent of human influence in

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https://doi.org/10.1016/j.quaint.2025.110047
Received 14 November 2024; Received in revised form 31 October 2025; Accepted 4 November 2025
Available online 14 November 2025

the region. The nearest archaeological evidence comes from Campo Laborde, located 7 km south of SPPL, where systematic excavations have documented lithic artifacts in direct stratigraphic association with megafauna remains, including a nearly complete *Megatherium americanum* skeleton bearing cut marks and impact fractures attributed to human activity (Politis et al., 2019). Among the identified taxa, several became extinct at different temporal intervals.

Paleoenvironmental research in the Interserrana area of the central Pampa is primary derived from archaeological contexts (Steffan et al., 2014; Scheifler et al., 2015; Politis et al., 2019), stratigraphical records (Fidalgo et al., 1991; Favier-Dubois et al., 2021), paleontological evidence (Prado and Alberdi, 1999; Prado et al., 2015, 2019), palynological data (Prieto, 1996; Tonello and Prieto, 2010) and isotopic studies (Bonadonna et al., 1995; Bellinzoni et al., 2023, 2024).

This study seeks to obtain paleoecological insights from gastropods remains recovered at SPPL. To achieve this, it is crucial to establish the origin of the gastropod fossils, reconstruct the pathways by which they entered the site, and analyze the pre- and post-burial taphonomic processes affecting these fossils and their enclosing sediments to properly characterize the depositional environments. This research forms part of a broader project aimed at evaluating faunal biodiversity through multiple proxies at SPPL, with the goal of analyzing environmental dynamics in the study area during the Quaternary period (Prado et al., 2019). The findings constitute a new paleoecological record that enhances our understanding of environmental conditions during the late Pleistocene to Holocene transition in the Interserrana region. The results from these bioindicator analyses, together with the geochemistcal data, are discussed in the context of other regional environmental records spanning the late Pleistocene chronology.

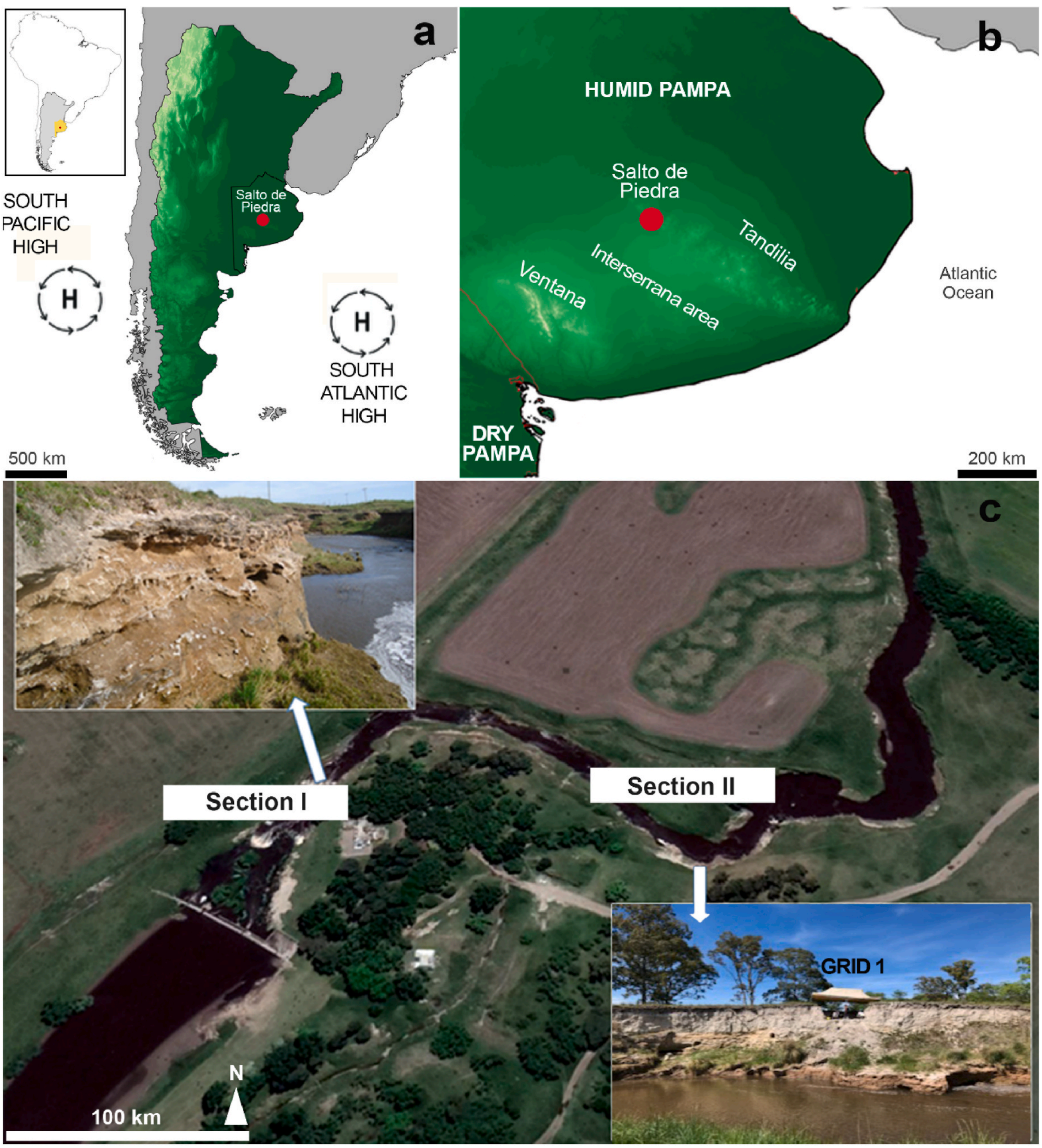


Fig. 1. a. Location map of Argentina and study site, b. Buenos Aires Province where Salto de Piedra site is located and the Interserrana area, Humid and Dry Pampas and c. Aerial view of the study site. The gastropods studied here come the sediment samples taken from Grid 1 excavation in section II of the Tapalqué creeck.

1.1. Environmental settings, stratigraphic and chronological context of Salto de Piedra

The Pampean Region encompassing the vast plain of central-eastern Argentina, intermittently interrupted by the low hills of the Ventana and Tandil systems (Fig. 1). Due to its geographic position, this region is regarded as an ecotone between the Brazilian and Patagonian sub-regions (Ringuelet, 1961; Morrone, 2001). Regional climatic dynamics are largely determined by the combined influences of the Atlantic and Pacific Oceans. The South Atlantic Anticyclone generates warm, humid winds from the north and northeast, while the air masses associated with the South Pacific Anticyclone bring cold, dry conditions from the south and southwest, (Iriondo et al., 2009). Within the Pampean Region, two major sub-area are recognized: the humid temperate prairies of the north and northeast (Humid Pampa) and the shrubby, semi-arid landscapes of the south and southwest (Dry Pampa).

The sedimentary succession exposed along the upper basin of the Tapalqué Creek provides valuable paleoenvironmental information on the late Quaternary climatic evolution of the Interserrana area (Favier-Dubois et al., 2021). The Salto de Piedra paleontological locality (36° 56′ 54.6″ S, 60° 22' 19.9" W), situated near Olavarría city in Buenos Aires Province, contains a rich assemblage of vertebrate and invertebrates fossils spanning the last 150,000 years: this study focuses on the Late Pleistocene record of the locality, located within the Humid Pampa sub-region (Fig. 1). Six principal depositional units (U) and twelve facies (F), representing distinct sedimentological sequence (Fig. 2). These cycles are defined by sedimentary discontinuities, including erosional unconformities and pedogenetic horizons, with each facies characterized by unique lithological attributes, reflecting the range of sub-environments conditions present during deposition (Favier-Dubois et al., 2021)

The Unit 4 and Unit 5 have been dated by ^{14}C on fossil bone remains and gastropods, yielding ages from 16,530–15,780 at the base to 12,833–12,533 cal y.BP on top (Prado et al., 2024; Bellinzoni et al., 2025).

This paper focused on the gastropod content from lithostratigraphic units U4 to U6 (F7 to F12, Fig. 2). The unit U4 is a brownish yellow to very pale brown (10 YR 6/6 to 10 YR 7/3 sensu Munsell soil color chart, 1994) sandy deposits with cross to horizontal bedding from F7 to F9. The base of U4 F8 has been dated by ^{14}C in (Favier-Dubois et al., 2021; Prado et al., 2024) on a rib of a horse *Equus neogeus*. Medium sand grades upward into fine sand and discrete lenses of fine gravel are visible at the bottom of this unit, which has a tabular geometry. Vertebrate remains and freshwater gastropods are abundant in some layers. This unit corresponds to Late Pleistocene fluvial deposits belonging to the Guerrero Member (upper section) of the Luján Formation (Fidalgo et al., 1973).

Lithostratigraphic unit U5 is a light gray to gray (2.5Y 7/1 to 2.5Y 6/1) sandy silt to silty clay deposit with horizontally laminated to massive structure and lenticular geometry, represented by F10 and F11 (Fig. 2). Diatoms (light gray layers) and freshwater mollusks are abundant in both facies of this unit (Favier-Dubois et al., 2021). The U5 unit overlays in erosive disconformity over U4. The U5-F11 unit was dated by ^{14}C on *Chilina parchappii* (Prado et al., 2024). The U5 unit corresponds to Early/Mid Holocene fluvio-lacustrine deposits that were correlated to the Río Salado Member of the Luján Formation (Favier-Dubois et al., 2021).

Lithostratigraphic unit U6 is a dark grayish brown (2.5Y 4/2) sandy

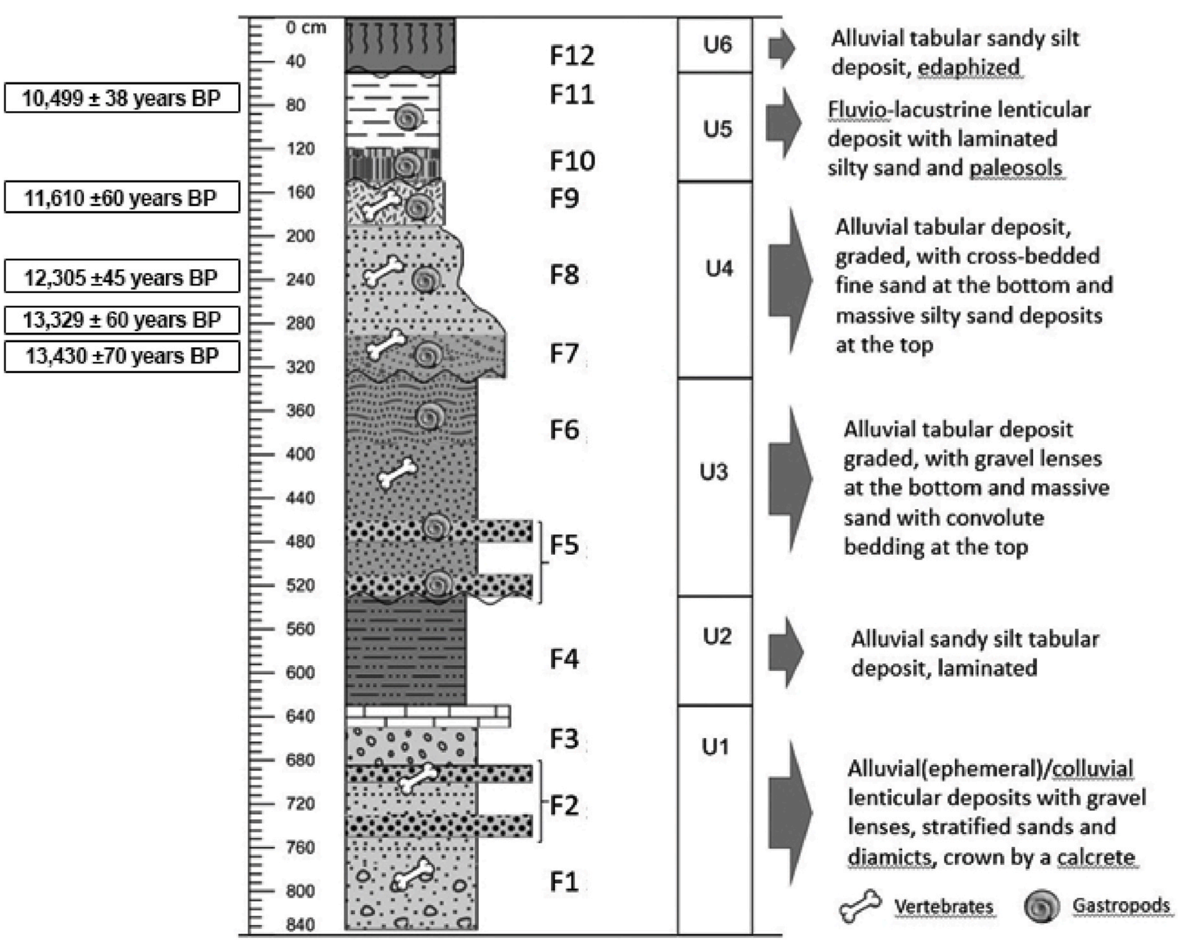


Fig. 2. Sedimentary composite stratigraphy of Salto de Piedra site of the Tapalqué stream and ^{14}C (AMS) dating of Units U4 to U5 from Prado et al. (2024) and Bellinzoni et al. (2025). Figure obtained from Favier-Dubois et al. (2021).

silt deposit with a granular structure and tabular geometry. These sediments were affected by pedogenesis in the form of a dark soil (Mollisol), well-drained, with a distinct an A-AC-C profile (Fig. 2). This unit corresponds to edaphic alluvial deposits (Favier-Dubois et al., 2021).

2. Materials and methods

The materials analyzed are stored in the INCUAPA-CONICET Collections, Facultad de Ciencias Sociales de la Universidad Nacional del Centro de la Provincia de Buenos Aires under the label FCS-IN. We report the initial findings obtained from taxonomic and taphonomic analyses of malacofauna remains from the upper stratigraphic section, collected during systematic excavations employing a terrestrial grid (Fig. 1). These excavations have reached stratigraphic units from Unit 4 (facies 8) up to Unit 6, facies 12 and 11 at the top (Favier Dubois et al., 2021). The gastropod specimens recovered from the excavation area grid (G1) was installed, with squares of 50 cm × 50 cm (Fig. 1d). A total of 24 successive spits of 10 cm thick each were excavated. The volume of sediment collected per sample is 0.025 m^3. The recovered sediment was wet sieved with a water pump, using a 0.5 mm mesh to recover micro-fossils. In addition, modern malacofauna specimens were collected following recommendations of Naranjo García and Gómez Espinosa (2004) from the neighboring area of Tapalqué Creek. In the lab, each sediment sample was dried, and the material was sorted and recovered picking up under a binocular lens (20x-40x Iroscope NZ-14T) or with the naked eye. Photography was taken with Leica S6D stereoscopic microscope with a high-resolution camera DMC4500 housed at INCUAPA. The SEM images have been taken in an INSPECT Low Vacuum microscope housed at the MNCN (CSIC, Spain).

The taxonomic identifications were based on categories at the supra genus level, as Bouchet et al. (2017) indicated. The geographical distribution of each species is defined by its ecological requirements, and the paleoecological interpretation is based on bibliographic information (Gaillard and Castellanos, 1976; Cazzaniga, 1982; Bonetto et al., 1986; Rumi, 1991; Castellanos and Miquel, 1980; Miquel and Steffan, 2005; Gutiérrez Grégoric et al., 2006; De Francesco and Hassan, 2009).

The relative abundance of individuals by species and by stratigraphic level was obtained through a quantitative analysis considering the complete and fragmented shells. The statistical tests applied to the gastropods were carried out using the software PAST (Hammer et al., 2001) to estimate sample richness and biodiversity values, which were calculated with the Shannon-Wiener (H) index. As sample sizes varied between units, a rarefaction analysis was applied to calculate these indices based on the smallest sample size. These results will provide complementary information on malacological heterogeneity (Buzas and Hayek, 2005; Martello et al., 2006; Erthal et al., 2015).

The preservation of the shells was evaluated from basic observations of taphonomic attributes. Taphonomic variables such as abrasion (Fernández-López, 2000), sedimentary infilling, crusting and coloration, were evaluated in the 30 % of the complete shells. The malacological fossil record consists in a total of 14,597 shells (11,272 complete and 3325 fragments) of species recovered from 13 sediment samples from Excavation 1 (G1) (Table 1 and Supplementary Information 1). The richness and diversity of the malacological assemblages were evaluated by grouping similar sample sizes according to their provenance across five stratigraphic levels, considering both the corresponding stratigraphic units and associated facies.

All the variables were classified into three different **categories** or degrees of modification except for coloration, in which only two categories; translucent and opaque (generally white) were considered. The color of transparent (T) layers can be recognized when viewed in white light. Opaque ones (O) reflect the light that they do not absorb.

Abrasion or mechanical wear on the surface of the shells, according to Fernández-López (2000) is usually produced by the impact of particles transported by water, wind, or by friction between the elements themselves that are moved. The different degrees of modification that correspond with this taphonomic variable is defined as follows: degree 0 (all ornamentation visible, absence of appreciable changes), degree 1 (>75 % of the whorl without alteration), degree 2 (<25 % without alteration).

Sedimentary infilling is recognized as the presence of infillings (sediment and shell fragments) inside the shells, considering the following degrees: degree 0 (empty), degree 1 (>50 % filling-in) and degree 2 (>75 % filling-in). Encrustation occurs when an element is covered with certain materials. Calcareous, phosphatic, or clayey crusts are frequent (e.g., calcium carbonate, $CaCO_3$). The categories distinguished for this variable are defined considering the suture of the whorl, which is the portion of the shell spire structure, separated by the suture lines of the shells.

Therefore, we have distinguished three grades as: degree 0 (without aggregations), degree 1 ($CaCO_3$ covering at least the 50 % of the suture of the whorl) and degree 2 ($CaCO_3$ completely cover the sutures of the whorl and along the whorl). Fragmentation was also evaluated considering the 30 % of the sample analyzed here. Finally, fragmentation was classified according to the following degrees: degree 0 (complete), degree 1 (loss of apex, whorl 2 and 3) and degree 2 includes only 25 % of the shell (Steffan et al., 2014).

Small samples of a few grams (250 gr) from each of the units (U4-F8, U4-F9, U5-F10, U5-F11) were taken from the excavation sections. Our aim was to compare the texture and chemical composition between the shell fill and the surrounding sediment of these units and facies. Chemical analyses of these sediments were carried out using energy dispersive spectrometry (EDS) and scanning electron microscopy equipment housed at the Museo Nacional de Ciencias Naturales (MNCN). Available Raman or X-R microdiffraction could not be applied to these samples because the sediment was loose and porous. These techniques required grain-by-grain analysis. We opted for EDS (energy dispersive spectrometry) to obtain a general chemical composition of a

Table 1
Malacological composition and diversity values of the Stratigraphical Profile 3 in Salto de Piedra Locality. Due to the small sample size recovered from U6-F12, the minimum sample size considered for the analyses comes from U4-F8 (n = 13).

		U6-F12		U5-F11		U5-F10		U4-F9		U4-F8	
Species	Environmental conditions	N	%	N	%	N	%	N	%	N	%
Miradiscops brasiliensis	Terrestrial	0	0 %	4	0 %	0	0 %	0	0 %	0	0 %
Succinea meridionalis	Palustrine	0	0 %	1266	33 %	5558	76 %	67	100 %	13	100 %
Heleobia parchappii	Fluvial/lacustrine	1	50 %	1090	28 %	606	8 %	0	0 %	0	0 %
Galba viator		0	0 %	17	0 %	21	0 %	0	0 %	0	0 %
Chilina parchappii		1	50 %	47	1 %	0	0 %	0	0 %	0	0 %
Biomphalaria peregrina		0	0 %	1463	38 %	1118	15 %	0	0 %	0	0 %
TOTAL		**2**		**3887**		**7303**		**67**		**13**	
TOTAL (%)		**0.02 %**		**34.48 %**		**64.79 %**		**0.59 %**		**0.12 %**	
Richness (n = 13)		–		3.193		2.598		1		1	
Shannon H (n = 13)		–		1.050		0.620		0		0	

sediment sample. To evaluate the lithostratigraphic geochemistry of the deposit, six variables were considered (pH, humidity, organic matter content, totals of carbonates, siliceous waste, conductivity and total dissolved salts) at the LAPREI laboratory (INCUAPA-CONICET). The quantitative evaluation of organic matter (OM) of mineral soils and sediments is done by determining the total carbon in soil-sediment (organic and inorganic carbon). For this, the Loss on Ignition (LOI) method is used, based on the protocol of Physical Geography Laboratories (Department of Geography, University of Cambridge) (Heiri et al., 2001). This method considers the loss of mass on ignition and the residues after it. For the determination of losses by calcination, the sample is taken to an oven at 105 °C to determine the % humidity and then in a muffle it is calcined at 450 °C to determine the %MO. Finally, at 950 °C to determine the % carbonates and % Siliceous Residue. The pH, electrical conductivity (mS, milli Siemens) and total dissolved salts (ppm, parts per million) are measured in soil solution according to the reference standard European Standard (Musztyfaga and Kabała, 2015) – ISO 10390:205 – EPA 9045D. These data set will allow us to evaluate dissolutions and other chemical weathering in each excavated level.

3. Results

3.1. Taxonomic and diversity analyses

Malacofaunal recovered is represented by six species of freshwater gastropods: *Heleobia parchappii* (Cochliopidae), *Galba viator* (Lymnaeidae)*, Chilina parchappii* (Chilinidae), *Biomphalaria peregrina* (Planorbidae), *Miradiscops brasiliensis* (Scolodontidae = Systrophiidae) and *Succinea meridionalis* (Succineidae) (Fig. 3; Table 1). The stratigraphic distribution of the taxa identified corresponds to the temporal interval covered by the Pleistocene to the Holocene periods until the present. The taxa *Heleobia parchappii*, *Galba viator*, *Chilina parchappii, Biomphalaria peregrina*, *Succinea meridionalis* have been recorded since the Pleistocene (Gaillard and Castellanos, 1976; Castellanos and Miquel, 1980; Rumi, 1991; Gutiérrez Gregoric et al., 2006; Steffan et al., 2014; Pisano and Fucks, 2016; MolluscaBase, 2025) and *Miradiscops brasiliensis* since the Holocene (Miquel and Steffan, 2005).

Brief yet comprehensive summaries of the ecological traits of the most abundant taxa, as well as those of particular paleoenvironmental significance (Fig. 3), are fundamental to strengthening interpretative

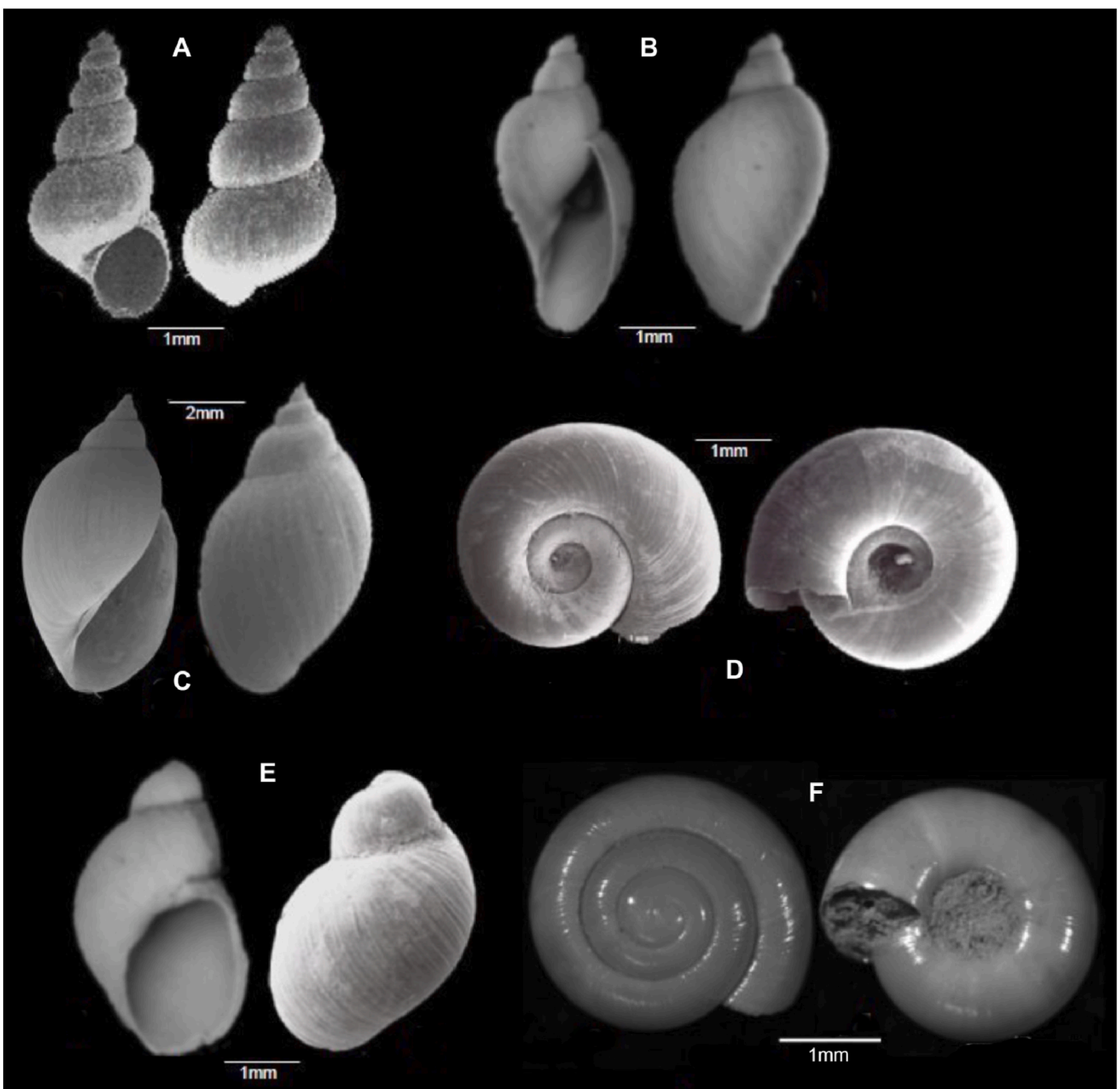


Fig. 3. References of molluscs species: A. *Heleobia parchappii*; B. *Galba viator*; C. *Chilina parchappii*; D. *Biomphalaria peregrina*; E. *Succinea meridionalis*; F. *Miradiscops brasiliensis*.

analyses. In the Pampean Region, *Heleobia parchappii* was detected across a broad spectrum of freshwater habitats, encompassing both lotic (streams, creeks) and lentic systems (lagoons, ponds) (Castellanos and Miquel, 1980). Its euryoic nature, characterized by tolerance to a wide range of environmental conditions—including salinity levels between 10 and 34 ‰—suggests a high ecological plasticity that enables persistence under fluctuating conditions (Tietze, 2011). Similarly, *Biomphalaria peregrina* occupies lentic environments and slow-flowing freshwater systems, but unlike *H. parchappii*, its abundance is strongly constrained by low temperatures, indicating a narrower thermal niche (Rumi, 1991; Gutiérrez Gregoric et al., 2006). In contrast, *Succinea meridionalis* represents a terrestrial component of the assemblage, thriving in habitats with abundant organic matter, leaf litter, and woody debris, which provide moisture and protection against desiccation. Its population dynamics appear closely tied to ambient humidity, with peaks likely occurring during wetter periods (Pisano and Fucks, 2016). Finally, *Miradiscops brasiliensis* also inhabits terrestrial habitats, particularly those with dense vegetative cover and moist microhabitats, and its occurrence in sedimentary records indicates relatively humid conditions—either persistent or episodic—under warm-temperate climates (Aguirre et al., 2011). Considering together, these species reflect a gradient of ecological strategies, ranging from broad tolerance and habitat generalist in aquatic taxa to moisture-dependent specialization in terrestrial forms, providing valuable indicators of past and present hydroclimatic conditions in the region.

The palustrine/terrestrial species, *Succinea meridionalis*, is dominant in most units (absent in U6), followed by freshwater species like *B. peregrina, H. parchappii*, *Ch. parchappii* and *L. viator.* The unit 4 is monospecific assemblage with only *S. meridionalis* recorded. In the U5 unit, diversity increases and a new taxon, the terrestrial species *M. brasiliensis* is recorded in U5-F11. The malacological association recovered from U6-F12 is a small sample with two shells of freshwater gastropods corresponding to *H. parchapii* and *C. parchappii*. Malacological abundances increase from U4 (facies F9 and F8) to U5-F10 where the highest abundance of gastropod remains is recorded. This abundance slightly decreases in U5-F11, and in U6-F12 drastically falls being the facies with lowest abundance registered in the Salto de Piedra sequence (Table 1).

Analyses of biodiversity were focused on U5-F11, U5-F10, U4-F9 and U4-F8. Richness and Shannon-Wiener (H) values obtained through rarefaction analyses are shown in Table 1. The richest sample comes from U5-F11, followed by U5-F10 and U4-F9, and U4-F8. Shannon index values indicate that the highest diversity is observed in U5-F11 followed by U5-F10, where six and four species were recorded, respectively. As only one species was recorded in both facies from the U4, the Shannon index values obtained were 0 in these facies, indicating the lowest diversity values amongst the units analyzed here. Therefore, diversity and richness increase from the bottom (U4-F8) to the top (U5-F11) of the sequence. The Non-Metric Multidimensional Scaling analysis results (Fig. 4) indicate that the facies from the U5 are more similar between them in malacofaunal composition than the facies from the U4, which also showed a great similarity between them. These differences are probably due to variations in the environmental conditions between units. The most dissimilar unit was U6, most likely due to the small sample size.

3.2. Taphonomic analysis

This taphonomic analysis was performed on samples recovered by wet sieving of sediments from the excavation of G1. This analysis allowed us to quantify the taphonomic characteristics of the shells. Non-wet sieved samples were also analyzed using the EDS spectrometry to compare the shell infilling and the surrounding sediment.

Abrasion, observed as the alterations of the ornamentation of the shells, was relatively low in all the studied units. Between 16 % and 25 % of the gastropods were classified as a degree 1 of abrasion in all the units and only in the U5 unit between 6 % and 4 % of the shells were classified as a degree 2.

The encrustation or formation of carbonate layers is especially notorious in the U4-F8 unit, with 50 % of shells encrusted (degree 2) (Table 2), especially with a thick carbonate layer on the surface of 4 shells recovered from the excavation of Grid 1 (G1). All the specimens from U4-F9 were unaffected by encrustation. In the upper part of the sequence, crusting increases from U5-F10 (14 %) to U5-F11 (44 %) in a

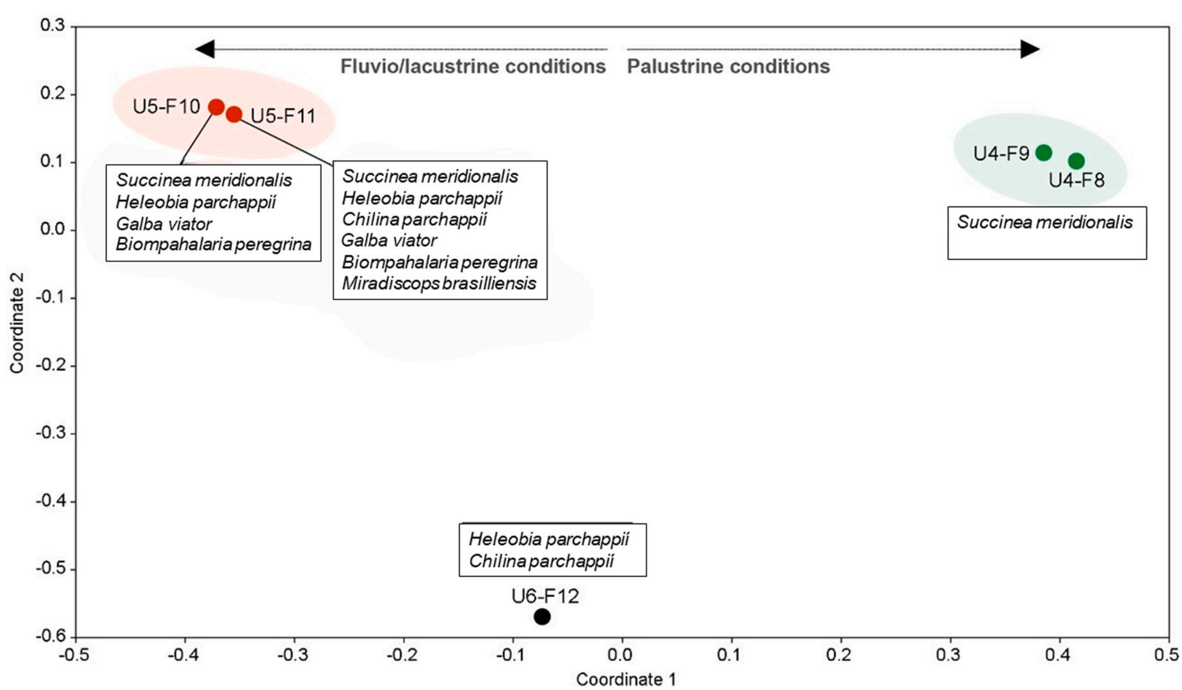


Fig. 4. Non-metric Multidimensional Scaling analysis showing the differences in faunal composition between units due to the different environmental conditions prevailing during the time when the sediments were deposited.

Table 2
Percentages of shells affected by the different taphonomic modifications observed in Salto de Piedra paleontological site.

Taphonomic variable	Degree	U5-F11	U5-F10	U4-F9	U4-F8
Abrasion	0 (0 %)	76 %	70 %	84 %	75 %
	1 (25 %)	20 %	24 %	16 %	25 %
	2 (75 %)	4 %	6 %	0 %	0 %
	TOTAL	**24 %**	**30 %**	**16 %**	**25 %**
Encrustation	0 (0 %)	51 %	85 %	100 %	25 %
	1 (50 %)	44 %	14 %	0 %	25 %
	2 (100 %)	5 %	1 %	0 %	50 %
	TOTAL	**49 %**	**15 %**	**0 %**	**75 %**
Sedimentary infilling	0 (0 %)	46 %	63 %	21 %	0 %
	1 (50 %)	35 %	1 %	5 %	0 %
	2 (75 %)	19 %	36 %	74 %	100 %
	TOTAL	**54 %**	**37 %**	**79 %**	**100 %**
Coloration	Opaque	99 %	99 %	100 %	100 %
	Transparent	1 %	1 %	0 %	0 %

grade 1. In this unit, there is a predominant presence of a fine dust layer (5 % of the sample, degree 2), which is mainly observed on *B. peregrina*.

The sedimentary infilling presents a differential pattern; in general terms, 100 % of the shells from U4-F8 have sediment inside and all the shells analyzed were classified in degree 2. In U4-F9 unit, sedimentary infilling is observed in 74 % of the gastropods, classified as a degree 2.

At the top of the sequence, these values decrease considerably. In unit U5-F10 most samples are empty (63 %) or in grade 2 (36 %) of the sample. Shells from U5-F11 appear in grade 1 (35 %) or grade 2 (19 %) with sediment at its interior. The main difference between these levels is that most of the fillings are classified as a degree 2 in F10, and as degree 1 in F11. Finally, opaque coloration is constant along the sequence analyzed.

Breakage was analyzed in *S. meridionalis*, *H. parchapii* and *B. peregrina* which are the main species recovered at the site (Table 3). Both facies from U4 (*Succinea* monospecific facies) showed 100 % of the specimens broken in degree 1. In U5-F10, 74 % of the shells of *S. meridionalis*, 91 % of *H. parchapii,* and 72 % of *B. peregrina* were broken. Breakage values from U5-F11 slightly decrease in comparison with U5-F10. Therefore, in unit 5 Facies 11, 67 % of the shells of *S. meridionalis* are broken, while the 89 % for *H. parchapii* and the 45 % for *B. peregrina* are in stage 1 or 2 of fragmentation.

3.3. Geochemistry

The results obtained from the geochemical analysis from each unit of the sequence show that the pH variation is not significant, and the values are alkaline between 8 and 8.8 (Table 4, Fig. 5, and Supplementary Information 2). Throughout the analyzed stratigraphic profile, the values of organic matter indicate variations between 2.68 % and 5.06 %. The lowest percentage in organic matter is observed in U4-F8. Analyzing the percentages from the bottom to the upper part of the profile, there is an increase of values (3.73 %) at mid U5-F11, and another increase is recognized on the top of that unit (4.89 %). As expected, the highest values of organic matter are recorded in U6-F12, the present-day soil vegetation cover.

Table 3
Percentage values obtained for each of the units and facies analyzed. Breakage is presented in relation to the three main species recovered from the paleontological site, from grade 0 (complete) to high fragmentation (grade 2 = 25 % of the shell).

Unit (U) - Facies (F)	*Succinea meridionalis*			*Heleobia parchapii*			*Biomphalaria peregrina*		
	Degree			Degree			Degree		
	0	1	2	0	1	2	0	1	2
U5-F11	32 %	33 %	34 %	12 %	41 %	48 %	55 %	30 %	15 %
U5-F10	26 %	45 %	29 %	9 %	61 %	30 %	27 %	27 %	45 %
U4-F9	–	100 %	–	–	–	–	–	–	–
U4-F8	–	100 %	–	–	–	–	–	–	–

Total carbonates have wide ranges of variation throughout the analyzed profile, their percentages vary between 5.4 % and 28.79 %. Total mean values indicate that the highest abundance of carbonates is detected in U5-F11 (Table 4). In fact, an increasing trend is observed from U4 to U5 while from U5 towards the top, carbonate percentage decreases.

An inversely proportional variation between siliceous waste and carbonate content is observed along the units analyzed. This relationship is especially remarkable in U5-F11, where the mean values of carbonate content is the highest and siliceous waste considerably low. Siliceous waste concentration varies between 70.18 % and 91.2 %. The lowest percentage is found in U5-F10 unit, and the highest values are recorded in U6-F12. Geochemistry results could also be related to the taxonomic composition of the units analyzed from the profile. A relationship between the highest content in carbonates observed in U5-F11 can be established with the increase in aquatic gastropod richness and diversity observed in this unit, where two new species are registered: *M. brasiliensis* and *C. parchappii*. The proportion of total dissolved salts varies between 200 and 375 (ppm) and the conductivity varies between 0.17 and 0.30 (mS). In both variables, the lowest values are recorded at the bottom and at the top of the sequence. Values increase from U4-F9 to U5-F10, and a reduction is observed from U5-F10 to the uppermost unit U6-F12.

Additionally, to data coming G1, other samples were collected in each stratigraphical facies (F8 to F11) from the stratigraphic profile. These samples were unwashed, allowing us to analyze the geochemistry and other relevant characteristics of the sediment contained within the shells corresponding. The sediment inside shells have been analyzed using energy dispersive spectrometry (EDS) to compare the chemical composition with the surrounding sediment. Sample taken from U4-F8 yielded no gastropod shells, confirming the low rate of fossil content from Facies 8. The sediment filling the shells in U4-F9 is sandy (Fig. 6a and b), with identical chemical composition to the sediment of the unit (Fig. 6c to e). Most gastropod shells from Unit 5-F10 content a silty muddy sediment with abundant diatoms as seen in the sediment (Fig. 7a–c). The chemical composition of the filling is almost identical than the sediment of U5-F10 unit (Fig. 7d and e), with only minor elemental differences (sulphur and phosphorus <1 %), but in general the two are very similar in texture and composition. Inside the shells of *S. meridionalis* the following diatoms species association was identified: *Campylodiscus clypeus*, *Caloneis westii*, *Surirella striatula* and *Tabularia fasciculata*. The U5-F11 unit gastropod shells may content sediment or smaller shells inside. The sediment infilling and the sediment of this facies is a mixed silty sediment with fewer diatoms (Fig. 8a–c) which have identical chemical compositions (Fig. 8d and e).

4. Discussion

4.1. Environmental changes inferred from the new analysis of gastropods

Results obtained from the different analyses carried out on the remains of invertebrates and geochemical data for each of the stratigraphic units allow us to characterize the depositional environments and the agents involved during sedimentation, as well as factors of preservation of the malacofauna. The information obtained will provide the paleoenvironmental conditions for the Late Pleistocene and Holocene of Salto de Piedra site.

Table 4
Geochemistry composition of each sampled level stratigraphic profile. Abbreviations: SD Standard deviation.

Unit (U) - Facie (F)	Values	pH	Humidity (%)	Organic matter (%)	Totals carbonates (%)	Siliceous waste (%)	CE (mS)	Total Dissolved Salts (ppm)
U6-F12	MIN	8	26.21	3.7	8.5	70.97	0.19	250
	MEAN	8.25	32.77	4.27	15.41	80.08	0.24	306.67
	MAX	8.5	39.54	4.89	27.13	87.69	0.29	350
	SD	0.19	4.69	0.39	6.87	6.11	0.03	34.16
U5-F11	MIN	8.4	32.67	2.75	10.5	72.76	0.24	300
	MEAN	8.47	36.07	3.07	20.14	77.36	0.27	336.65
	MAX	8.5	40.99	3.38	26.16	86.73	0.3	375
	SD	0.05	3.61	0.25	5.44	4.84	0.02	26.22
U5-F10	MIN	8.6	26.56	3.04	8.74	70.18	0.27	325
	MEAN	8.62	32.77	3.47	18.14	77.93	0.28	343.58
	MAX	8.7	41.61	3.73	28.79	87.9	0.29	350
	SD	0.05	6.39	0.31	8.41	7.39	0.01	12.50
U4-F9	MIN	9	16.38	2.68	13.53	83.96	0.21	250
	MEAN	9.00	17.98	2.71	13.75	84.20	0.21	262.20
	MAX	9	19.74	2.75	13.97	84.44	0.22	275
	SD	0.00	2.38	0.05	0.31	0.34	0.01	17.68

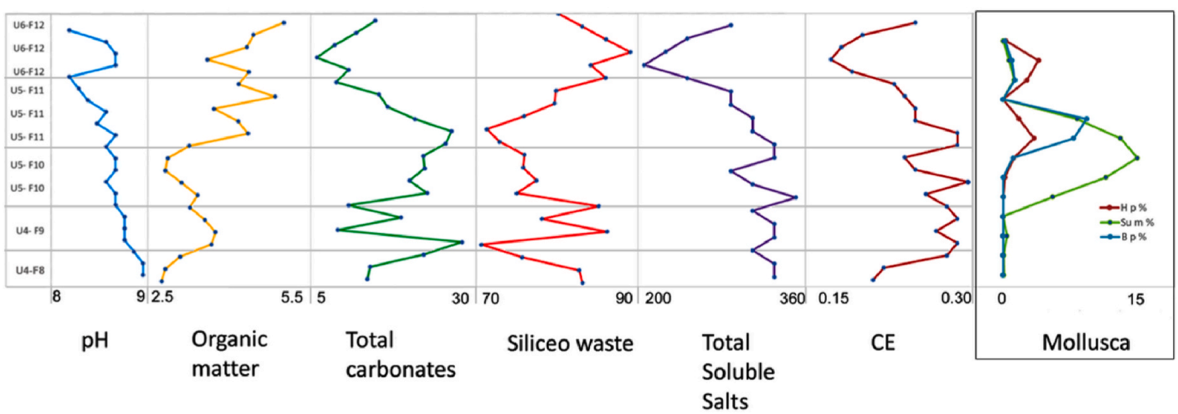


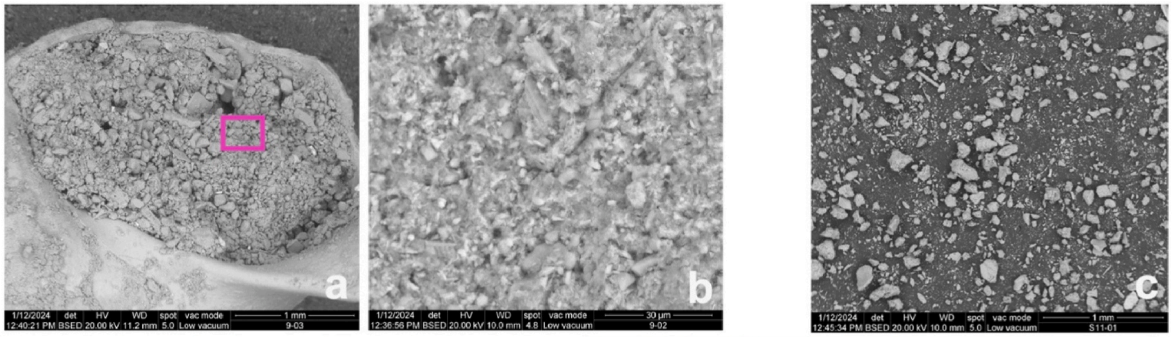
Fig. 5. Summary of malacological assemblage and geochemistry results linked to local stratigraphical profile.

In the stratigraphical units U4-F8 and U4-F9, a monospecific assemblage represented by *S. meridionalis* has been recovered. The taphonomic analyses and ecological characteristics of this species allow us to infer water-saturated or swampy (palustrine) environments *in situ*. Stagnant and slow-moving swampy environments are usually characterized by anoxic conditions. Therefore, reducing conditions prevailed and can be inferred from the analysis of the mollusks of this unit. These conditions are not favorable for a high diverse aquatic faunal assemblage (Espinosa and De Francesco, 2003), a fact that could explain the low diversity and low shell content observed in unit 4. A current study about the resilience of invertebrates (Jenkins and Boulton, 2007) proposes a low density of taxa after prolonged periods without periodic flooding events because entrance of fresh-water currents is not frequent. The presence of a massive silty sand substrate with low porosity possibly linked to muddy surfaces can be related to habitat swampy. In U4 the presence and abundance of *Succinea meriodinalis* coincides with the wide tolerance of this species to salinity changes. The total dissolved salts indicate lower values which suggest greater aridity.

Previous stratigraphic studies recognize a minor erosional discordance between U4 and U5, probably related to periods of fluvial reactivation (Favier-Dubois et al., 2021). In the stratigraphic unit U5-F10, mixed environmental conditions are inferred. On the one hand, there is a predominance of *S. meridionalis* which indicates swampy environments (Pisano and Fucks, 2016). On the other hand, an increase in diversity and richness is observed in U5 compared to U4 with new taxa such as *H. parchappii*, *G. viator,* and *B. peregrina*. These facies are the richest in the sequence. The entrance of these taxa is probably due to the existence of water currents coming from the near creeks located in the area. Taphonomic variables observed in the malacological record, considering the sedimentary filling inside the shells could indicate that gastropods from U5 could remain floating for a time and gradually filled with suspended sediment and diatoms (U5-F10). The autecology of these diatom species indicates their presence in brackish conditions in a shallow body of water (Maidana, 1994, Espinosa and Beilinson, 2017). Likewise, *Tabularia fasciculata* is halophilic, alkaliphilic, epontic (i.e., lives attached to the substrate), benthic and lives preferably under eutrophic (high nutrient content) conditions. The microenvironmental characteristics of these species are consistent with those inferred from *S. meridionalis* autecology and geochemistry.

The development of a water body with lacustrine characteristics can be inferred through the reduction of *S. meridionalis* and the increase of other species such as *H. parchappii* and *B. peregrina*. This flooding event may have favored the entrance of these and other species increasing the diversity values in these facies with respect to the others.

In U5-F11, the sedimentological analysis indicates lacustrine environments and the presence of a diatomite. However, taphonomic analysis of the shells suggests some turbulence by relative high-energy pulses. These events could be indicated by the variations of the



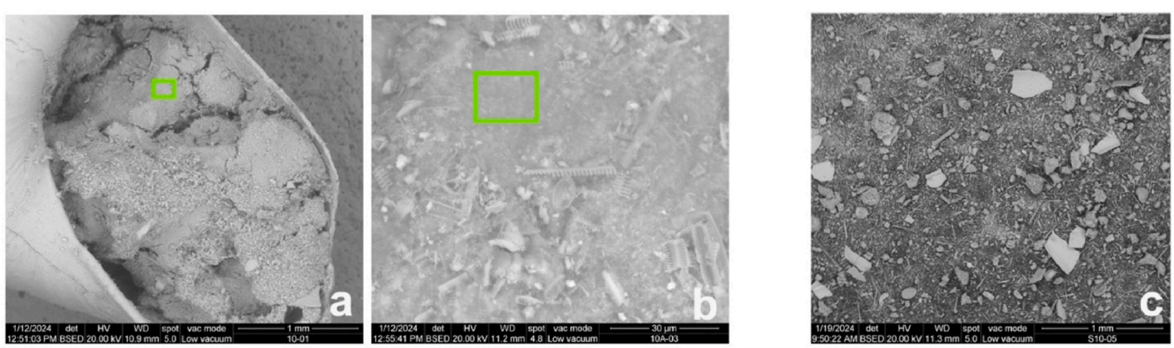
Element	App	Intensity	Weight%	Weight%	Atomic%	Compd%	Formula	Number
G9	Conc.	Corrn.		Sigma				of ions
Na K	2.14	0.8038	1.93	0.15	1.80	2.61	Na2O	0.23
Mg K	1.65	0.7368	1.62	0.12	1.43	2.69	MgO	0.18
Al K	7.62	0.8314	6.64	0.16	5.28	12.55	Al2O3	0.68
Si K	33.78	0.8390	29.19	0.26	22.29	62.44	SiO2	2.86
K K	2.73	0.9968	1.98	0.11	1.09	2.39	K2O	0.14
Ca K	9.61	0.9503	7.33	0.16	3.92	10.25	CaO	0.50
Ti K	0.69	0.7978	0.62	0.10	0.28	1.04	TiO2	0.04
Fe K	4.82	0.8264	4.23	0.20	1.62	6.04	Fe2O3	0.21
O			46.46	0.32	62.29			8.00
Totals			100.00					
							Cation sum	4.84

d

Element	App	Intensity	Weight%	Weight%	Atomic%	Compd%	Formula	Number
S9	Conc.	Corrn.		Sigma				of ions
Na K	1.20	0.7890	1.61	0.28	1.52	2.17	Na2O	0.20
Mg K	1.14	0.7301	1.65	0.24	1.47	2.74	MgO	0.19
Al K	4.92	0.8257	6.30	0.29	5.06	11.90	Al2O3	0.65
Si K	22.25	0.8396	28.01	0.48	21.63	59.93	SiO2	2.79
K K	1.83	1.0060	1.92	0.21	1.07	2.32	K2O	0.14
Ca K	8.56	0.9556	9.47	0.34	5.12	13.24	CaO	0.66
Ti K	0.46	0.7953	0.61	0.22	0.28	1.02	TiO2	0.04
Fe K	3.65	0.8264	4.67	0.41	1.81	6.68	Fe2O3	0.23
O			45.75	0.61	62.03			8.00
Totals			100.00					
							Cation sum	4.90

e

Fig. 6. a. Gastropod recovered from U4-F9. b. Detail of the sandy infilling, diatoms almost absent, fragmented and dispersed in the sediment; c. Sediment from U4-F9; d. Proportions of chemical elements from the infilling (squared in pink); e. Chemical composition of the stratigraphic unit U4-F9. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)



Element	App	Intensity	Weight%	Weight%	Atomic%	Compd%	Formula	Number
G10	Conc.	Corrn.		Sigma				of ions
Na K	0.90	0.8377	0.80	0.13	0.73	1.08	Na2O	0.09
Mg K	6.86	0.7746	6.57	0.16	5.66	10.90	MgO	0.72
Al K	6.24	0.7965	5.82	0.16	4.52	10.99	Al2O3	0.58
Si K	33.34	0.8202	30.17	0.26	22.49	64.55	SiO2	2.87
S K	0.25	0.7289	0.26	0.08	0.17	0.65	SO3	0.02
Cl K	0.25	0.6851	0.28	0.08	0.16	0.00		0.02
K K	2.28	0.9752	1.74	0.10	0.93	2.09	K2O	0.12
Ca K	2.93	0.9391	2.32	0.11	1.21	3.24	CaO	0.15
Ti K	0.37	0.8052	0.34	0.08	0.15	0.57	TiO2	0.02
Fe K	4.40	0.8270	3.95	0.18	1.48	5.65	Fe2O3	0.19
O			47.75	0.32	62.49			7.98
Totals			100.00					
							Cation sum	4.77

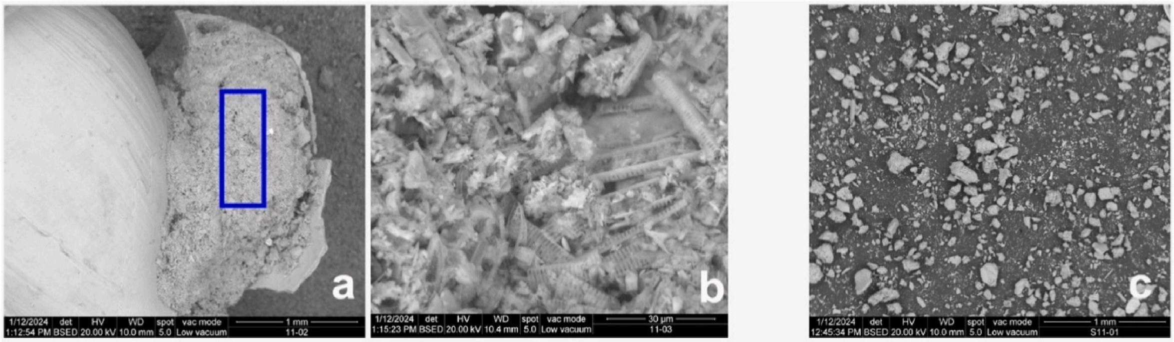
d

Element	App	Intensity	Weight%	Weight%	Atomic%	Compd%	Formula	Number
S10	Conc.	Corrn.		Sigma				of ions
Na K	0.72	0.8353	0.65	0.10	0.59	0.87	Na2O	0.08
Mg K	6.20	0.7753	5.98	0.13	5.16	9.91	MgO	0.66
Al K	5.75	0.8049	5.34	0.13	4.15	10.09	Al2O3	0.53
Si K	34.20	0.8317	30.75	0.22	22.98	65.79	SiO2	2.93
P K	0.30	0.8955	0.25	0.09	0.17	0.57	P2O5	0.02
Cl K	0.32	0.6869	0.34	0.07	0.20	0.00		0.03
K K	2.26	0.9772	1.73	0.08	0.93	2.08	K2O	0.12
Ca K	4.11	0.9397	3.27	0.10	1.71	4.58	CaO	0.22
Ti K	0.34	0.8026	0.31	0.07	0.14	0.52	TiO2	0.02
Fe K	4.04	0.8261	3.66	0.15	1.38	5.23	Fe2O3	0.18
O			47.71	0.26	62.59			7.97
Totals			100.00					
							Cation sum	4.74

e

Fig. 7. a. Gastropod recovered from U5-F10. b. detail of the infilling: silty sediment covered by abundant filamentary diatoms. c. Sediment of U5-F10. d. Proportions of chemical elements from the infilling (squared in green); e. Chemical composition of the stratigraphic unit U5-F10. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

percentage of sand (0 and 64 %) registered in the F11 in stratigraphic profile 2, the closest to the G1 excavation (Favier Dubois et al., 2021). Consequently, the scale of these water inflows, linked to variations in the flow of the stream course, is evident in this floodplain. These water inflows do not constitute a sedimentary structure, but rather that it is a massive deposit, which generated the displacement of some remains (microvertebrates and aquatic gastropods). In the U5-F11 unit, malacological studies suggest a rapid burial, possibly linked to these higher



Element	App	Intensity	Weight%	Weight%	Atomic%	Compd%	Formula	Number
G11	Conc.	Corrn.		Sigma				of ions
Na K	0.61	0.7743	0.63	0.13	0.61	0.85	Na2O	0.08
Mg K	1.76	0.7317	1.92	0.12	1.75	3.19	MgO	0.23
Al K	3.18	0.8251	3.07	0.13	2.52	5.81	Al2O3	0.33
Si K	30.08	0.8768	27.36	0.25	21.59	58.52	SiO2	2.81
K K	1.30	1.0322	1.01	0.09	0.57	1.21	K2O	0.07
Ca K	22.79	0.9685	18.76	0.22	10.38	26.26	CaO	1.35
Fe K	2.99	0.8201	2.91	0.18	1.16	4.16	Fe2O3	0.15
O			44.33	0.30	61.42			8.00
Totals			100.00					
							Cation sum	5.03

d

Element	App	Intensity	Weight%	Weight%	Atomic%	Compd%	Formula	Number
S11	Conc.	Corrn.		Sigma				of ions
Na K	0.44	0.7964	0.77	0.33	0.72	1.03	Na2O	0.09
Mg K	1.04	0.7463	1.93	0.30	1.71	3.19	MgO	0.22
Al K	2.56	0.8366	4.23	0.32	3.39	7.98	Al2O3	0.43
Si K	19.00	0.8701	30.15	0.57	23.20	64.49	SiO2	2.97
K K	0.90	1.0073	1.23	0.25	0.68	1.49	K2O	0.09
Ca K	8.57	0.9556	12.38	0.44	6.68	17.33	CaO	0.86
Fe K	1.87	0.8222	3.14	0.46	1.21	4.48	Fe2O3	0.16
O			46.18	0.70	62.40			8.00
Totals			100.00					
							Cation sum	4.82

e

Fig. 8. a. Gastropod recovered from U5-F11. b. Detail of the infilling, silty sediment mixed with diatoms. c. Sediment from U5-F11. d Proportions of chemical elements from the infilling (squared in blue); e. Chemical composition of the sediment from U5-F11. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

energy flows carrying mollusks and sediments. Richness and diversity values are the highest in this unit, probably due to the heterogeneity of environments associated with the superimposition of different events of accumulation as a result of transport processes.

In the U5-F11 unit a calibrated age of 12,531–12,613 years BP was obtained (Prado et al., 2024). These facies are characterized by a fluvio-lacustrine environment, with highly fragmented *H. parchappi* shells, while the presence of *B. peregrina* and *L. viatror* show very good preservation and were associated with a small isolated channel structure that was recorded during the excavation. Comparison between sediment at the interior of the shell and the outer sediment is identical and contains the highest abundance of diatoms. This lenticular feature filled with fine-grained sediment (bottom of U5-F11), may be related to the formation of an isolated channel structure from which the lacustrine conditions developed. The high taxonomic diversity and richness (middle part of U5-F11) may indicate a flood event. The characteristics inferred for this sector of the stratigraphic profile correspond to a change in fluvial deposit and wetter paleoenvironmental conditions. Towards the upper sector, the development of vegetated soil surfaces of variable expression is inferred due to the appearance of terrestrial species in the malacological record. Considering the geochemistry, in U5-F11, the highest percentage of calcium carbonate concretions is recorded here, and this could be generated by oversaturation of the waters (Fernández et al., 2025: 61).

The U6-F12 unit, was affected by pedogenesis in the form of discrete thin buried A horizons (mollisol) (Favier-Dubois et al., 2021), and geochemistry results show high values of organic matter accumulation in accordance with the current soil development and disconnected from floodplain because of this valley was carved out. This situation has been recorded for immediate environments to some rivers in arid conditions (Valett et al., 2005). This leads to a severe depletion of dissolved oxygen levels that inhibits the appearance of invertebrates (Dana et al., 1988). Taking these studies into account, the decrease in humidity contribution to these sectors of the landscape could account for the absence or reduction of malacological diversity in these contexts. Considering that the calcium carbonate content decreases in humid climate conditions, then this would explain the pulse recorded in U6-F12. This situation is synchronous with a change in pH and the increase in silica. If this change was linked to increased rainfall, it is not possible to link it directly to a rise in the watercourse or to water runoff, characteristic of this area and accumulation in topographically lower sectors.

In summary, the specific analyses carried out for Grid1 at the base of the analyzed profile (between U4-F8 and U5-F11), indicate fluctuation of terrestrial and swamp environments. In situ environment indicates species related to the lacustrine sector of low energy (U5-F10). However, at the contact between U5-F10 and the base of U5-F11, a minor erosive event linked to a higher energy current is recorded. This includes transportation and re-sedimentation of remains (gastropods and micro vertebrates). Chemical composition of sediment (EDS) at the interior of the shells and durrounding sediment is identical, allowing us to discard any potential reworking of these shells in U4-F9, U5-F10 and U5-F11.

This succession of swampy environments for the contact between the U4 and U5 correlated with the transition of Guerrero and Rio Salado Members is consistent with other profiles analyzed (Steffan et al., 2014; Prado et al., 2015), at Campo Laborde and La Moderna archaeological sites (Politis et al., 2019). Campo Laborde archaeological site is located on the left side bank of a tributary in the upper basin of the Tapalqué stream. Previous malacological studies carried out in Campo Laborde indicate that *S. meridionalis* is mainly recorded on top of the Guerrero Member. The Campo Laborde site presents an accepted well-dated context at 10.655 ± 35 ^{14}C years BP (*ca.* 12.600 cal years BP) (Politis et al., 2019). Similar ^{14}C ages measured in the shells have been obtained from Salto de Piedra site from U4 and U5 transition (Prado et al., 2024). Subsequently in the stratigraphic sequence, in the soil horizons develops from sediments of the Río Salado Member (U5-F11), there is evidence of a notable decrease in *S. meridionalis* species, and the record of *B. peregrina*, suggests the transition from marshy conditions to lacustrine conditions. Above this level, no malacological remains are recovered in eolian sediments corresponding to the La Postrera Formation (Steffan et al., 2014).

4.2. Comparison of data with the other isotopic signal and paleoecology from megamammals

The presence of arid conditions in the region is linked to a sparse vegetation cover (Prieto, 1996; Grill et al., 2007). Recently, Bellinzoni et al. (2023) evaluated the isotopic signal and paleoecology of a latest Pleistocene megamammal sample from the Salto de Piedra Paleontological Locality and compares it with mollusk isotopic data (Bonadonna et al., 1995). Based on statistically more positive values of the megamammal sample related to the modern meteoric water sources' oxygen isotopic composition, these authors inferred that arid and cold climatic conditions persisted until ca. 16-13 ka cal. BP (a similar age obtained from Equus neogeus bone sample from unit 4-Facies 8 dated with 14C, Prado et al. (2024). At the same time, Bonadonna et al. (1995) show that Succinea has the most positive δ18O values, which is related to its ecology being more prone to the effects of evaporation in arid conditions.

In their isotopic studies, Bellinzoni et al. (2023) saw that the Xenarthrans, mammal group, shows an oxygen isotopic composition clearly and statistically different from the sample linked to arid and cold conditions. The Xenarthrans have the most negative $\delta^{18}O$ values in agreement with isotopic values of fossil remains from the archaeological sites La Moderna and Campo Laborde (Politis and Gutiérrez, 1998; Politis et al., 2019) located a few kilometers from Salto de Piedra. Both contexts are recorded between the sediments of the Guerrero and Río Salado members, for which isotopic, sedimentological, and pollen evidence suggests a time of higher humidity (Bonadonna et al., 1995; Prieto, 1996; Favier-Dubois et al., 2021, Steffan et al., 2014). Accordingly, Bellinzoni et al. (2023) also proposed that the most negative $\delta^{18}O$ values of the Xenarthrans could be reflecting climatic conditions with greater humidity and precipitation before the Pleistocene/Holocene transition (*ca.* 13-11 ka cal. BP).

In short, these paleoenvironmental inferences are consistent with other records of pollen and vertebrate fauna (e.g., Grill et al., 2007; Prado et al., 2001) from sites in the southeast of the Interserrana area. These surveys record shifts toward swamp and floodplain vegetation at the beginning of the Holocene and with those that suggest sub-humid-dry conditions for the center of the Pampean region (e.g., Prieto, 1996; Zárate et al., 2000; Quattrocchio et al., 2008).

5. Conclusions

The integration of different malacological, taphonomic and geochemical analyses in the Tapalqué stream basin indicated that the assemblages come from two different environments recognized in the floodplain deposits. At the Pleistocene boundary of Salto de Piedra, palustrine deposits are recognized in the upper sections of U4 and fluvio-lacustrine deposits in U5. U4 corresponds to arid conditions with water-saturated surfaces.

In the stratigraphical unit U5-F10, a change in malacological record is observed towards a greater development of flooded and swampy environments, especially related to the low-energy. Nevertheless, at the contact between U5-F10 and at the base of U5-F11, an erosive event linked to a higher energy current is recorded. This includes transport and re-sedimentation of shells (malacofauna). Reworking has been discarded by the taphonomic, chemical composition and dating of gastropod shells from these stratigraphic units (U4 and U5) and facies (F8 to F11). The development of palustrine and lacustrine facies, linked to events of greater availability of water in the environment, correspond to the depositional dynamics of the Late Pleistocene-Holocene boundary. 'The results from Grid1 mark a trend in the record and they warrant a comparison with records from other grids and sampling stratigraphic sections along the upper course of the Tapalqué stream.

CRediT authorship contribution statement

Pamela Steffan: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Gustavo N. Gómez:** Writing – original draft, Investigation. **Sara García-Morato:** Writing – review & editing, Formal analysis. **Jonathan E. Bellinzoni:** Writing – review & editing, Formal analysis. **Ricardo Bonini:** Writing – review & editing, Formal analysis. **Cristian M. Favier-Dubois:** Writing – review & editing, Formal analysis. **Claudia I. Montalvo:** Writing – review & editing. **María Teresa Alberdi:** Writing – review & editing. **M. Dolores Marin-Monfort:** Writing – review & editing. **Yolanda Fernandez-Jalvo:** Writing – review & editing, Supervision, Funding acquisition. **José Luis Prado:** Writing – review & editing, Supervision, Funding acquisition.

Declaration of competing interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial Support for this work that could have influenced its outcome.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing publication, with respect to intellectual property. It so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

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Acknowledgments

This work has been made possible thanks to Research Project from Ministerio de Ciencia e Innovación CGL2022_PID2021-126933NB-I00 and from the Consejo Superior de Investigaciones Científicas i-COOP2021_COOPB20589 of Spain; Agencia Nacional de Promocion Científica y Técnica (I+D+i) PICT 2019–03480, Consejo Nacional de Investigaciones Científica y Técnicas (CONICET, PUE-0079) and Special Grant from the National University of Central Argentina (UNICEN) to INCUAPA. The authors are very grateful to comments and suggestions from the anonymous reviewers and the QI Editor, Hema Achyuthan, that have greatly improved this paper. We are also thankful to the Editor in Chief of the QI, Pierluigi Pieruccini, and the editor Rosa M. Albert.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quaint.2025.110047.

References

Aguirre, M.L., Miquel, S.E., González, C.A., Kröhling, D., Zucol, A.F., Brea, M., Eastoe, C., 2011. Malacofauna continental holocena y paleoambientes en Villa Valle María (Diamante, Entre Ríos, Argentina). Geobios 44, 1–17. https://doi.org/10.1016/j.geobios.2010.06.003.

Bellinzoni, J.E., Valenzuela, L.O., Prado, J.L., 2023. Feeding habits of a latest Pleistocene megamammal community. A synecological perspective by stable isotopes analysis. J. S. Am. Earth Sci. 129, 104496. https://doi.org/10.1016/j.jsames.2023.104496.

Bellinzoni, J.E., Valenzuela, L.O., Bonini, R.A., Fuchs, L., Gómez, G.N., Steffan, P.G., Prado, J.L., 2024. An isotopic approach for assessing synergies among extinction

drivers on Late Pleistocene megafauna in the Argentine Pampas. J. Archaeol. Sci.: Report 58, 104687. https://doi.org/10.1016/j.jasrep.2024.104687.
Bellinzoni, J., Bonini, R., García-Morato, S., Gómez, G.N., Steffan, P., Marín-Monfort, M. D., Zurita, A., Cuadrelli, F., Prevosti, F.J., Fernández, F.J., Favier-Dubois, C., Rafuse, D.J., Alberdi, M.T., Fernandez-Jalvo, Y., Prado, J.L., 2025. New mammal assemblage from last interglacial in Argentine Pampas: debating biostratigraphic and biochronological reliability. Quat. Sci. Rev. 367, 109511. https://doi.org/10.1016/j.quascirev.2025.109511.
Bonadonna, F.P., Leone, G., Zanchetta, G., 1995. Composición isotópica de los fósiles de gasterópodos continentales de la provincia de Buenos Aires. In: Alberdi, M.T., Leone, G., Tonni, E.P. (Eds.), Evolución Biológica Y Climática En La Región Pampeana Durante Los Últimos 5 Millones De Años. CSIC, pp. 77–104.
Bonetto, A., Tassara, M., Rum, A., 1986. Australis n. subgen. de *Diplodon spix* (Bivalvia, Unionacea) y posibles relaciones con *Hyriidae australianos*. Bol. Soc. Biol. Concepcion 57, 55–61.
Bouchet, P., Rocroi, J.P., Hausdorf, B., Kaim, A., Kano, Y., Nützel, A., Parkhaev, P., Schrödl, M., Strong, E.E., 2017. Revised classification, nomenclator and typification of gastropod and monoplacophoran families. Malacologia 61 (1–2), 1–526. https://doi.org/10.4002/040.061.0201.
Buzas, M.A., Hayek, L.A.C., 2005. On richness and evenness within and between communities. Paleobiology 31 (2), 199–220. https://doi.org/10.1666/0094-8373(2005)031[0199:oraewa]2.0.co;2.
Castellanos, Z.J.A., Miquel, S.E., 1980. Notas complementarias al género *Chilina gray* (Mollusca Pulmonata). Neotropica 26 (76), 171–178.
Cazzaniga, N.J., 1982. Notas sobre hidróbidos argentinos II (Gastropoda Rissoidea). Una *Littoridina* del grupo *parchappii* en Península Valdés (Chubut). Revista del Museo de La Plata. Sección Zoología 129, 11–16.
De Francesco, C.G., Hassan, G.S., 2009. The significance of molluscs as paleoecological indicators of freshwater systems in central-western Argentina. Paleogeograph. Paleoclimatol. Paleoecol. 274 (1–2), 105–113. https://doi.org/10.1016/j.paleo.2009.01.003.
Erthal, F., Kotzian, C.B., Simoes, M.G., 2015. Multistep taphonomic alterations in fluvial mollusk shells: a case study in the Touro passo formation (Pleistocene-Holocene), southern Brazil. Palaios 30 (5), 388–402. https://doi.org/10.2110/palo.2013.104.
Espinosa, M.A., Beilinson, E., 2017. Diatomeas pleistocenas de la cuenca inferior del Río Quequén Salado. Ameghiniana 54 (4), 67.
Espinosa, M., De Francesco, F., 2003. Reconstrucción paleoambiental de depósitos costeros holocenos del sureste de la provincia de. Revista de Paleolimnología 29, 49–60.
Favier-Dubois, C., Herrera, D., Villegas, R., Bonini, G.N., Gómez, P., Steffan, M., Vax, A., Flores, J., Bellinzoni, M.T., Alberdi, J.L., 2021. Alluvial deposit stratigraphy from the Salto de Piedra paleontological locality (Argentine Pampas): evidences from last glacial-interglacial cycles. Neues Jahrbuch Geol. Palaontol. Abhand. 299, 29–48. https://doi.org/10.1127/njgpa/2021/0953.
Fernández, F.J., García-Morato, S., Gómez, G., Fernández-Jalvo, Y., Prado, J.L., 2025. Rediscovery of an extinct species of caviine rodent of the Late Pleistocene after the Last Glacial Maximum in the Pampasic Domain (Argentina). Mammalia. https://doi.org/10.1515/mammalia-2025-0020.
Fernández-López, S.R., 2000. Temas de Tafonomía. Universidad Complutense de Madrid. https://webs.ucm.es/centros/cont/descargas/documento11157.pdf.
Fidalgo, F., De Francesco, F., Colado, U., 1973. Geología superficial en las Hojas Castelli. Actas V Congreso Geológico Argentino 4, 27–39.
Fidalgo, F., Riggi, J.C., Gentile, R., Correa, H., Por Ro, N., 1991. Los "Sedimentos postpampeanos" con tinentales en el ámbito sur bonaerense. Rev. Asoc. Geol. Argent. 46, 239–256.
Gaillard, C., Castellanos, Z.A., 1976. Mollusca gasteropoda hydrobiidae. In: Ringuelet, R. A. (Ed.), Fauna De Agua Dulce De La República Argentina, vol. XV. FECIC, pp. 1–40, 2.
Gómez, G.N., Fernández, F.J., García-Morato, S., Marín-Monfort, M.D., Montalvo, C., Steffan, P., Bellinzoni, J., Bonini, R., Alberdi, M.T., Fernandez-Jalvo, Y., Prado, J.L., 2025. Times of changes, the latest Pleistocene micromammal association of the Salto de Piedra site (Buenos Aires Province, Argentina). Quat. Res. in press.
Grill, S., Borromei, A., Martínez, G., Gutierrez, M.A., Cornou, M.E., Olivera, D., 2007. Palynofacial analysis in alkaline soils and paleoenvironmental implications: the Paso Otero 5 archaeological site (Necochea district, Buenos Aires province, Argentina). J. S. Am. Earth Sci. 24 (1), 34–47. https://doi.org/10.1016/j.jsames.2007.02.010.
Gutiérrez Gregoric, D.E., Núñez, V., Rumi, A., Roche, M.A., 2006. Freshwater gastropods from del Plata Basin, Argentina, checklist and new locality records. Comunicaciones de La Sociedad Malacolológica de Uruguay 9 (89), 51–60.
Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001. PAST: paleontological statistics software package for education and data analysis. Paleontologia Electronica 4 (1). http://palaeo-electronica.org/2001_1/past/issue1_01.htm.
Heiri, O., Lotter, A.F., Lemcke, G., 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. J. Paleolimnol. 25, 101–110. https://doi.org/10.1023/A:1008119611481.
Iriondo, M., Brunetto, E., Kröhling, D., 2009. Historical climatic extremes as indicators for typical scenarios of Holocene climatic periods in the Pampean plain. Paleogeograph. Paleoclimatol. Paleoecol. 283 (3–4), 107–119. https://doi.org/10.1016/j.paleo.2009.09.005.
Jenkins, K.M., Boulton, A.J., 2007. Detecting impacts and setting restoration targets in arid-zone rivers: aquatic micro-invertebrate responses to reduced floodplain inundation: Arid-zone river restoration. J. Appl. Ecol. 44 (4), 823–832. https://doi.org/10.1111/j.1365-2664.2007.01298.x.
Maidana, N.I., 1994. Diatomeas en sedimentos cuaternarios del arroyo Tapalqué (Buenos Aires, Argentina). Lista de especies y sus abundancias relativas. Notas Científicas y Técnicas. Fundación Carl C Zon Caldenius 10, 1–8.
Martello, A.R., Kotzian, C.B., Simões, M.G., 2006. Quantitative fidelity of recent freshwater mollusk assemblages from the Touro Passo River, Rio Grande do Sul, Brazil. Iheringia. Serie Zoologia 96 (4), 453–465. https://doi.org/10.1590/s0073-47212006000400010.
Miquel, S.E., Steffan, P.G., 2005. Hallazgo de Retidiscus reticulatus (Gastropoda Pulmonata Charopidae) en la Argentina, un posible indicador de paleoclima húmedo Holoceno en el sur bonaerense. Ameghiniana 42 (2), 495–500. http://www.scielo.org.ar/scielo.php?script=sci_arttext&pid=S0002-70142005000200019&lng=es&tlng=es.
MolluscaBase eds. (2025). Galba viator (A. d'Orbigny, 1835). en: https://molluscabase.org/aphia.php?p=taxdetails&id=1065075.Consultadoel12/09/2025.
Morrone, J.J., 2001. Biogeografía de América Latina y el Caribe. Manuales y Tesis *SEA*, 3.
Musztyfaga, E., Kabała, C., 2015. Lithological discontinuity in glossic planosols (Albeluvisols) of lower silesia (SW Poland). Soil Sci. Annual 66 (4), 180–190. https://doi.org/10.1515/ssa-2015-0035.
Naranjo-García, E., Gómez-Espinosa, C., 2004. Moluscos. In: Bautista-Zúñiga, F. (Ed.), Técnicas De Muestreo Para Mejoradores De Recursos Naturales. CIGA.
Pisano, M.F., Fucks, E.E., 2016. Quaternary mollusc assemblages from the lower basin of Salado River, Buenos Aires Province: their use as paleoenvironmental indicators. Quat. Int.: J. Int. Union Quater. Res. 391, 100–111. https://doi.org/10.1016/j.quaint.2015.07.022.
Politis, G.G., Gutiérrez, M.A., 1998. Gliptodontes y Cazadores-Recolectores de la Region Pampeana (Argentina). Lat. Am. Antiq. 9 (2), 111–134. https://doi.org/10.2307/971990.
Politis, G.G., Messineo, P.G., Stafford Jr., T.W., Lindsey, E.L., 2019. Campo Laborde: a Late Pleistocene giant ground sloth kill and butchering site in the Pampas. Sci. Adv. 5 (3), eaau4546. https://doi.org/10.1126/sciadv.aau4546.
Prado, J.L., Alberdi, M.T., 1999. The mammalian record and climatic change over the last 30,000 years in the Pampean Region, Argentina. Quat. Int. 57–58, 165–174. https://doi.org/10.1016/s1040-6182(98)00057-3.
Prado, J.L., Alberdi, M.T., Azanza, B., Sánchez, B., 2001. Climate and changes in mammal diversity during the late Pleistocene-Holocene in the Pampean Region (Argentina). Acta Paleontologica Polonica 46, 261–276.
Prado, J.L., Martínez- Maza, C., Alberdi, M.T., 2015. Megafauna extinction in South America: a new chronology for the Argentine Pampas. Paleogeograph. Paleoclimatol. Paleoecol. 425, 41–49. https://doi.org/10.1016/j.paleo.2015.02.026.
Prado, J.L., Bonini, R., Favier-Dubois, C., Gómez, G.N., Steffan, P.G., Alberdi, M.T., 2019. Fossil horses from the Late Pleistocene of Tapalqué Creek (Buenos Aires Province, Argentina). Neues Jahrbuch Für Geologie Und Palaontologie. Abhandlungen 294 (3), 285–305. https://doi.org/10.1127/njgpa/2019/0860.
Prado, J.L., Duval, M., Demuro, M., Santos-Arévalo, F.J., Alberdi, M.T., Tomassini, R.L., Montalvo, C.I., Bonini, R., Favier-Dubois, C.M., Burrough, S., Bajkan, S., Gasparini, G.M., Bellinzoni, J., Fernández, F.J., García-Morato, S., Marin-Monfort, M.D., Adams, S., Zhao, J., Beilinson, E., Fernández-Jalvo, Y., 2024. Refining the chronology of Middle/Late Pleistocene fossil assemblages in the Argentine Pampas. Quat. Sci. Rev. 344, 108958. https://doi.org/10.1016/j.quascirev.2024.108958.
Prieto, A.R., 1996. Late Quaternary vegetational and climatic changes in the Pampa grassland of Argentina. Quat. Res. 45 (1), 73–88. https://doi.org/10.1006/qres.1996.0007.
Quattrocchio, M.E., Borromei, A.M., Deschamps, C.M., Grill, S.C., Zavala, C.A., 2008. Landscape evolution and climate changes in the Late Pleistocene–Holocene, southern Pampa (Argentina): evidence from palynology, mammals and sedimentology. Quat. Int.: J. Int. Union Quater. Res. 181 (1), 123–138. https://doi.org/10.1016/j.quaint.2007.02.018.
Ringuelet, R.A., 1961. Rasgos de la zoogeografía de la Argentina. Physis 22 (63), 151–170.
Rumi, A., 1991. La familia *Planorbidae rafinisque*, 1815 en la República Argentina. Fauna de agua dulce de la República Argentina 15, 5–51.
Scheifler, N., Messineo, P., Pardiñas, U., 2015. Implicancias tafonómicas y paleoambientales de los pequeños vertebrados del sitio arqueológico Campo Laborde (centro de los pastizales pampeanos). ARCHAEOFAUNA 24, 197–208.
Steffan, P.G., Aguirre, M.L., Miquel, S.P., 2014. Malacofauna Continental Holocene (Región Pampeana, Argentina). Rev. Bras. Palaontol. 17 (2), 225–248.
Tietze, E., 2011. Distribución de *Heleobia parchappii* en ambientes dulceacuícolas de la Región Pampeana (Argentina). Sociedad Malacológica De Chile (SMACH), Amici Molluscarum, Número Especial, pp. 73–75.
Tonello, M.S., Prieto, A.R., 2010. Tendencias climáticas para los pastizales pampeanos durante el Pleistoceno tardío-Holoceno: estimaciones cuantitativas basadas en secuencias polínicas fósiles. Ameghiniana 47 (4). https://doi.org/10.5710/amgh.v47i4.7, 501–478.
Zárate, M.A., Kemp, R., Espinosa, M., Ferrero, L., 2000. Pedosedimentary and paleoenvironmental significance of a Holocene alluvial sequence in the southern Pampas. Argentina. Holocene 10, 481–488. https://doi.org/10.1191/095968300669846317.