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TAPHONOMIC SIGNATURE OF *GLYCYMERIS LONGIOR* SHELLS (BIVALVIA) AND ITS POTENCIAL AS PALEOENVIRONMENTAL PROXY FOR QUATERNARY NORTHERN PATAGONIA (ARGENTINA)

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Short Description: Preservation patterns of *G. longior* assemblages corresponded to various water flow energies, resulting in distinct carbonate precipitation.

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Abstract. One of the most abundant species of bivalves found on modern beaches and Quaternary deposits in the San Matías Gulf (SMG, Patagonia Argentina, SW Atlantic Ocean) is *Glycymeris longior.* Its high abundance and broad geographical distribution turn *G. longior* into a target species for taphonomical studies. Here, we described the taphonomic signature registered on its shells from San Antonio Bay (SMG, Rio Negro). This study will contribute to future taphonomic comparisons in the SW Atlantic Ocean, as well as in other Quaternary deposits and provide insight about the spatial variation of the taphonomic processes influenced by the ambient environment. *Glycymeris longior* valves from the Holocene Punta Delgado deposits showed two taphonomic signatures whose shell assemblages were differentiated by fragmentation, rounding and cementation intensities. Shells from PD2018A and PD2018B (two sampling localities representing similar environment) were subject to continuous and low energy water flow. Those remained in a low intensity hydrodynamic sediment-water interface that would favour high shell cementation. On the other hand, shells from PD2016 were also subject to continuous, but more energetic water flow. Those would remain in the taphonomic active zone for enough time to confer smooth edges and to be colonized by clionid sponges but not enough favourable for carbonate precipitation. Punta Delgado site was interpreted as a protected area during the Holocene (last 4200 yrs.) similar to the modern one, but with differences in carbonate precipitation as the product of differences in water flow intensities. Finally, the high mechanical resistance of *G. longior* shells, together with its abundance and broad geographical distribution turn this species into a suitable target taxon for further taphonomic and ecologic analyses and comparisons.

Keywords. *Glycymeris longior*. Taphonomy. Cementation. Spit bars. Bay. Macrotidal regime. Patagonia. Quaternary.

Resumen. PERFIL TAFONÓMICO DE VALVAS DE *GLYCYMERIS LONGIOR* (BIVALVIA) COMO PROXI PALEOAMBIENTAL PARA EL CUATERNARIO DE PATAGONIA NORTE (ARGENTINA). Una de la especies de bivalvos más abundantes que habita en la playas y depósitos cuaternarios del Golfo San Matías (GSM, Patagonia argentina, Océano Atlántico sud occidental) es *Glycymeris longior*. Su gran abundancia y amplia distribución geográfica, hace que *G. longior* sea una especie objetivo para estudios tafonómicos. Por lo cual, describimos el perfil tafonómico que registran sus valvas en la Bahía San Antonio (GSM, Argentina) con el objetivo de contribuir a futuras comparaciones tafonómicas, con material de playas actuales o de depósitos cuaternarios donde esta especie se encuentre. Las valvas de *G. longior* de los depósitos holocenos de Punta Delgado mostraron dos patrones de preservación diferentes caracterizados por diferencias en la intensidad de fragmentación, redondeamiento y cementación de sus valvas. Las valvas de PD2018A y PD2018B estuvieron sometidas a un flujo de agua continuo y poco intenso. Éstas permanecieron en la interfase sedimento-agua con menor intensidad hidrodinámica lo que favorecería a una alta cementación. Por otro lado, las valvas de PD2016 estuvieron sujetas también a un flujo de agua continuo, pero más intenso o energético. Éstas permanecerían en la TAZ el tiempo suficiente para producir bordes redondeados y ser colonizadas por las esponjas cliónidas pero no lo suficientemente para la precipitación de carbonatos. El sitio Punta Delgado se interpretó como una zona protegida durante el Holoceno (últimos 4200 años) similar a la actual, pero con diferencias en la precipitación de carbonatos

como producto de las distintas intensidades del flujo de agua. Finalmente, la alta resistencia mecánica de las valvas de *G. longior*, junto con su abundancia y amplia distribución geográfica convierten a esta especie en un taxón adecuado para análisis y comparaciones futuras.

Palabras clave. *Glycymeris longior*. Tafonomía. Cementación. Espigas litorales. Bahía. Régimen macromareal. Patagonia. Cuaternario.

THE SAN MATÍAS GULF (SMG), located on the northeastern coast of Patagonia (Fig. 1.1), Argentina, has a rich mollusc fossil record throughout the Quaternary. To the north of the SMG, at 40°45'S, the semicircular San Antonio Bay encompasses modern and old coastal environments with muddy tidal flats and spits of gravel and sand (Carbone *et al.* 2007). The morphology of the bay is a result of a submerged depression and the development of coastal features such as spit bars and beach ridges throughout the Quaternary transgressions and regressions (Angulo *et al.* 1978; Rutter *et al.* 1989, 1990; Favier-Dubois & Kokot 2011; Fucks *et al.* 2012; Mouzo 2014). A detailed study of the comparative taphonomy of molluscan shell assemblages may provide insight about the Quaternary coastal dynamics in which these deposits developed.

Modern and Quaternary molluscan assemblages from beaches associated to soft bottoms from San Antonio Bay are characterized by the predominance of two bivalve species: *Eucallista purpurata* (commonly known as *Amiantis purpurata*) that dominates the eastern side of the bay, and *Glycymeris longior* on the western side. In previous studies, taphonomic and paleoecologic analyses of *E. purpurata* allowed the reconstruction of the paleoenvironmental conditions during the Quaternary (Bayer *et al.* 2013, 2015, 2016) in those assemblages where this species was dominant. Physical, biological and even anthropogenic factors would have changed through time coinciding with local and global events such as: the Last Glacial Maximum, the final configuration of the coast of the SMG, and the Holocene Climatic Optimum (Bayer *et al.* 2016, 2020). At the same time, *G. longior* is an abundant species in the Quaternary marine coastal assemblages and modern beaches. Empty *G. longior* valves are found in high proportions on the beach; their shells are some of the most robust and resistant in the

112 mollusc assemblages (López *et al.* 2008; Boretto *et al.* 2013; Bayer *et al.* 2016). This
113 species presents a broad continuous geographical distribution from Pará State (Brazil) in
114 the north to the northern SMG in Argentina (Farinati 1978; Rocha & Matthews-Cascon
115 2014; WoRMS Editorial Board 2023), and it is found in great abundance in the study
116 area. The advantage of considering a target species for taphonomic analysis, i.e. the
117 same species from different assemblages throughout the same region, is the elimination
118 of interspecific variations associated with intrinsic factors such as the shell´s
119 microstructure, life habits and behavior, among others (Bayer *et al.* 2016, 2019). Thus,
120 the purpose of this study is to describe the taphonomical signature registered on *G.*
121 *longior* shells from San Antonio Bay (SMG, Rio Negro), as a target species to
122 contribute to future taphonomical comparisons in SW Atlantic Ocean, as well as in
123 other Quaternary deposits in which it can be found. Also, we evaluated the geology and
124 geomorphology of the San Antonio Bay area, together with taphonomic interpretations,
125 to understand the depositional environment and timing of the deposits.
126
127 **MATERIAL AND METHODS**
128 **Study area**
129 The SMG is the largest gulf in Patagonia, and one of the largest in South America
130 (Moreira *et al.* 2009). This gulf constitutes a semi-enclosed depression, whose bottom,
131 with depths close to 200 m, exceeds those corresponding to the edge of the shelf for that
132 same latitude (Pierce *et al.* 1969; Gagliardini *et al.* 2005; Ruiz Etcheverry *et al.* 2016;
133 Gordillo *et al.* 2018). Its water circulation behaves as a clockwise coastal eddy
134 predominantly influenced by tidal currents (Lanfredi & Pousa 1988; Tonini & Palma

2011), resulting in a protected area. . The San Antonio Bay is located in the north-western area of the SMG (40°42'/40°50' S and 64°43'/65°07' W) (Fig. 1.1), partially closed off by two spit bars (Fucks *et al.* 2012; Kokot & Favier-Dubois 2017). It corresponds to a tidal marsh (Carbone *et al.* 2007) which can be described as shallow inland marine waters, predominantly oriented parallel to the coast, separated from the ocean by a barrier, and connected to the open sea by one or more restricted inlets. At the inlet of San Antonio Bay, a tidal delta develops to depths of 14 m (Aliotta *et al.* 2000). This bay is characterized by semidiurnal tides. It has a macrotidal regime which can reach 9.22 m maximum in spring tide (SHN 2018).

The study site, Punta Delgado (40°45'10.89" S; 64°54'57.58" W), is located in the western spit bar of the internal area of San Antonio Bay (Fig. 1.2). Punta Delgado is a Pleistocene marine spit bar with Pleistocene and Holocene beach ridges composed mainly of mollusc shells, along with gravel and sand overlain by modern dunes (Angulo *et al.* 1978; Fucks *et al.* 2012; Kokot & Favier-Dubois 2017).

Geological background of the SMG

The SMG is located between the southwestern end of the Colorado Basin and the Somuncurá Plateau elevations (Fig. 2). This depression can be considered part of the Salinas Trapalcó-Laguna Curicó Lineament with an NW-SE trend (Fig. 2.1) (Turner & Baldis 1978; Gregori *et al.* 2008). The San Antonio bay itself would be one of these depressions (embayments) repeatedly flooded during the Quaternary (Porro & Fidalgo 1982; González Díaz & Malagnino 1984; Kokot & Favier Dubois 2009). The successive Quaternary transgressive and regressive episodes imprinted different geomorphological features (Angulo *et al.* 1978; Martínez *et al.* 2001; Fucks *et al.* 2012) such as beach

158 ridges, spits, littoral barriers, broad tidal flats, marshes and sandbanks (Fig. 2.3). The
159 San Antonio Bay is a tidal delta separated from the sea by two spit bars (Punta Delgado
160 to the West and Península Villarino to the East). They are elongated sand, gravel and
161 shell barriers that extend laterally through the construction of progradational beach
162 ridges (Davis & FitzGerald 2004). Along this internal channel, accumulative areas are
163 recognize forming curvilinear shore beach ridges (Fig. 1.2 and 1.3). This curvilinear
164 pattern is the consequence of refracted waves propagating through an inlet channel and
165 into the back-barrier region (Hine 1979; Costas & FitzGerald 2011; Isla *et al.* 2023). In
166 particular, sampling localities are located on the northern margin of the Punta Delgado
167 spit bar (Fig. 1.2).
168 Feruglio (1933, 1950) was the first to described the complete morphology, lithology,
169 palaeontology and relative chronology of the Quaternary marine terraces throughout
170 most of the Argentinean Patagonia coast. Then, Angulo et al. (1978) divided the
171 quaternary stratigraphy into two lithostratigraphic units: Baliza de San Matías and San
172 Antonio formations (Fig. 2.2) and assigned them to Pleistocene and Holocene
173 respectively. Regarding age control, these units were dated using radiocarbon dating
174 techniques (Angulo *et al.* 1981) with ages ranging between 27 ka and 40 ka, but this can
175 only provide a minimum age constraint to the Pleistocene. Rutter et al. (1989, 1990)
176 provided Aminostratigraphy and Electron Spin Resonance (ESR) dating from some
177 locations and concluded that deposits located at 24 m a.m.s.l. yielded ages between 169
178 ka and 230 ka (MIS 7), 83.2 ka-111 ka for deposits at 10 m a.m.s.l (MIS 5), and 66.8-
179 70.3 ka for beach rock (abrasion) platform at 0 m a.m.s.l. Both Baliza de San Matías
180 Fm. (MIS7) and San Antonio Fm. (MIS5e) are therefore assigned to the Pleistocene.

Based on these studies, Fucks et al. (2012) summarized the presence of four transgressive events. The oldest transgressive event corresponds to Marine Isotope Stage 9 (≥MIS 9?) and its deposits are found 60-70 m a.m.s.l. and 10 km northwest of San Antonio Oeste on the Provincial Road 2. The transgressive episode during the middle Pleistocene (MIS 7, between 230 and 190 ka) was identified at three locations: Caleta Falsa, Baliza Camino and northwest of San Antonio Oeste (Angulo *et al.* 1978; Rutter *et al.* 1989, 1990). In San Antonio Bay MIS 5e (about 130-115 ka) shoreline deposits and landforms are located between 12-8 m a.m.s.l. (Rutter *et al.* 1989, 1990; Gowan *et al.* 2021) and covered the spit bars and the beach ridges (Baliza San Matías, Puerto de Vialidad, La Rinconada, and on Provincial Road 2 near Gas Station). The coast was an open sea environment subject to a tidal regime. During the Last Glacial Maximum (LGM, 25–20 ka) (Hulton *et al.* 2002) the bay completely emerged, and beach ridges were successively formed as the sea level dropped. From the early Holocene (~11 ka) to the present the San Antonio Bay has been more protected from the open sea (Ponce *et al.* 2011; Fucks *et al.* 2012). In San Antonio Bay beach ridges below 10 m a.m.s.l. are designated as Holocene, and beach ridges at higher altitudes as Pleistocene. In particular, coarse sediments beach ridges in San Antonio Bay were formed during high-energy storm waves inundating the coast (Carter, 1988; Taylor & Stone, 1996; Tamura, 2012). They are formed mainly by shells with scarce sand matrix. Beachface in Punta Delgado and Punta Perdices tends to be steeper (~23°) due to coarser grain sizes (Bristow and Pucillo, 2006).

Autoecology of *Glycymeris longior*

Glycymeris longior is a warm-temperate species whose modern distribution extends from Pará State (Brazil) to the northern SMG in Argentina (Farinati 1978; Rocha & Matthews-Cascon 2014; WoRMS Editorial Board 2023). It is an infaunal suspension feeder living in fine and medium sandy bottoms, partially covered by small shell particles (Ituarte 1979; Scarabino *et al.* 2006; Gimenez *et al.* 2020*a*, *b*). The southernmost living population is found at El Sótano, in the NW sector of the SMG (Fig. 2.3), at water depths from 6 to 20 m (Scarabino 1977), where sea water temperature ranges from 8.3ºC (in August) to 22.2ºC (in January), and salinity ranges from 34 to 36 ‰ (Pascual *et al.* 2001). The *G. longior* fossil record extends back to the late Pleistocene in San Antonio Bay but has also been found in Quaternary deposits from Buenos Aires province, Uruguay and Brazil (Farinati 1978; Lorenzo & Verde 2004; Clavijo *et al.* 2005; de Souza *et al.* 2010; Lopes *et al.* 2013; Bayer *et al.* 2016; Martínez *et al.* 2016).

Study materials

The material was collected from two Holocene beach ridges at Punta Delgado (Fig. 1.2), where *G. longior* is the most abundant species in the shell assemblages (Fig. 3). Samples were collected superficially by hand at the top of the beach ridges. In order to compare the taphonomic profile of different shell assemblages, samples were collected by hand from 0.25 m^2 surface quadrat at two different beach ridges: PD 2016 and PD 2018A. Then, in order to compare sampling methods, we collected a third sample in the same beach ridge as PD2018A. The third sample, PD2018B, represented 10 meters of a continuous line transect (50 cm wide) of collecting superficially also by hand. These

225 samples contained materials bigger than 2 mm size. Deposits did not show evidence of
226 cementation nor consolidation.
227 **Taphonomic attributes studied in *Glycymeris longior***
228 For the choice of taphonomic attributes and taphonomic grades corresponding to this
229 species, various sources were consulted (Brett & Baird 1986; Kidwell *et al.* 1986;
230 Kidwell & Bosence 1991; Gordillo *et al.* 1993; Kowalewski *et al.* 1995; Zuschin et al.
231 2003; Gordillo 2009; Ritter *et al.* 2013, 2016; Bayer *et al.* 2016, 2019, among others).
232 The taphonomic attributes of the specimens were described using taphonomic grades
233 when quantifiable, or binary character states. In binary character states, zero
234 corresponds to a low-impacted or pristine state while one corresponds to an altered state
235 (Fig. 4; Supplementary material).
236 Fragmentation. This attribute is associated with shell breakage due to the action of
237 mechanical stress. It can be influenced by waves (Hollmann 1966; Parsons & Brett
238 1991; Smith & Nelson 2003) and biological interactions such as predation and
239 bioturbation (Zuschin *et al.* 2003). This attribute was coded as not fragmented (0), shell
240 breakage lower than 30% of the intact shell surface area (1), or shell breakage higher
241 than 30% (2).
242 Corrosion. This attribute was coded as original ornamentation (0) or corroded (1) when
243 superficial ornamentation was lost, or surface shell layers were exposed.
244 Rounding. This attribute is associated with exposure time. Shells may not lie far from
245 their point of origin but may have rolled back and forth over long distances (Smith &
246 Nelson 2003). Such oscillation of shells produces worn shell edges. Rounding was
247 classified as no rounding (0), and shells with rounded edges (1).

Domichnia traces. Some bioerosion structures were recognized on *G. longior* valves, that can be assigned to the dwelling traces (Domichnia) ethological category. Bioerosion structures found on infaunal bivalves, such as *G. longio*r, are normally produced *post-mortem* and after suffering transport, particularly after disarticulation (Santos & Mayoral 2008). *Post-mortem* traces was coded as no presence (0), and presence (1).

Other taphonomic attributes were coded as presence (1) or absence (0), namely external surface cementation and internal surface cementation. Right and left valves were not discriminated because they do not have significant assymmetry in shell sculpture (Chattopadhyay et al. 2013).

To explore differences in taphonomic signals among samples from different beach ridges and sampling method, we used a non-metric multidimensional scaling analysis (NMDS) calculated on Bray-Curtis dissimilarity index (square-rooted to made metric). This analysis was inplemented with the metaMDS function in the 'vegan' package (version 2.6-4) for R software. We used a Multivariate Analysis of Variance with Permutation (PERMANOVA) (Anderson 2001; Warton et al. 2012) with 9999 permutations to test for significant differences in preservation of bivalve assemblages between the three samples. We carried out PERMANOVA with Bonferroni correction for multiple comparissons, to test whether the three samples differ in preservation pattern. All statistical tests were conducted in the R program (R Development Core Team 2023, version 4.3.0).

RESULTS

We collected 517 valves of *G. longior* for the taphonomical study. Sample PD2016 contained 354 valves, PD2018A contained 73 valves and PD2018B had 90 valves. The NMDS ordination clearly segregated PD2016 from PD2018A and PD2018B (Fig. 5), with PD2018A and PD2018B exhibiting more tightly clustered in the NMDS bi-dimensional space/representation, with respect to sample PD2016.

PERMANOVA test also demonstrated significant differences between sample PD2016 with respect to PD2018A and PD2018B ($p<0.0001$; $F= 42.22$). However, samples PD2018A and PD2018B, collected with different methodologies (see Mat & Met section), showed no significant differences between them (Table 1). Therefore, both sampling methods did not show significant differences, then, did not contribute to the definition of preservation patterns.

Two preservation patterns could be observed in samples' preservation profiles (Fig. 6). In one hand, PD2016 was characterized by high fragmentation (67%) and low rates of internal and external cementation (6 % and 14 % respectively). Also, it showed low rounding rate (64%).

On the other hand, PD2018A and PD2018B were characterized by lower fragmentation (34% and 32% respectively) than PD2016. Also, PD2018A and PD2018B showed higher rates of rounding (93% and 96% respectively), presence of internal cementation (91% and 94% respectively) and external cementation (86% and 95% respectively) than PD2016.

However, shells from all three samples showed high rates of corrosion (PD2016: 89%; PD2018A: 84%; PD2018B: 100%) and high presence of Domichnia traces (PD2016: 65%; PD2018A: 70%; PD2018B: 76%) (Fig. 6).

Therefore, there were two taphonomic patterns: PD2016 with high fragmentation and low cementation; while PD2018A and PD2018B with low fragmentation but high rounding and high degree of cementation.

DISCUSSION

The samples of *G. longior* shells from Punta Delgado showed two types of preservation patterns which allow for the reconstruction of the paleoenvironment in the Holocene of the SMG. The environmental factors affecting the different assemblages have left a signatture on the shell preservation at a different intensity (according to Brett & Baird 1986; Kidwell & Bosence 1991; Bayer et al. 2019).

The Punta Delgado (SMG) samples showed high percentages of bioerosion represented by dwelling traces. These trace fossils, present in more than 65% of *G. longior* shells, were probably produced by clionaid sponges (Bromley 2004; Belaústegui *et al.* 2012; Gastaldi *et al.* 2018). *G.* is an infaunal bivalve which excavates shallow in the sediment (Scarabino 1977), and lives buried on the first centimeters of it (Gimenez *et al*. 2020). On the other hand, sponges are epifaunal organisms; therefore these dwelling traces would have been made when *G. longior* shells were exhumed and exposed on the seafloor. Thus, colonization by sponges must took place after the death of the *G. longior* shells. After death, the valves were exhumed, disarticulated and separated facilitating the settlement of these bioeroders on shell surfaces (Santos & Mayoral 2008; Belaústegui *et al.* 2018). Exhumed infaunal bivalve shells would be expected to have encrustation on interior surfaces only after their death and exhumation (Lescinsky *et al.* 2002). Moreover, most of the *G. longio*r shells showed a high intensity of *post-mortem*

316 traces, reflecting that these shells were exposed to the water-sediment interface for a
317 sufficient amount of time, allowing bioeroders to colonize the valves (Bromley *et al.*
318 1990; Lescinsky *et al.* 2002; Santos & Mayoral 2008). That slow initial colonization
319 would be carried out by these boring organisms during the first 1-2 years (Bromley &
320 De Alessamdro 1990; Bromley *et al.* 1990; Peyrot-Clausade *et al.* 1995; Walker *et al.*
321 1998). Moreover, *G. longior* shells exhibited a high boring intensity, which may
322 indicate that these shells were exposed to the sediment-water interface for several years
323 after death at least once, either by storms, tides or wave action and/or bioturbation
324 (Parsons-Hubbard *et al.* 1999; Rodland *et al.* 2006). According to the taphonomic
325 profile of the assemblages, we suggest here that exhumation of shells could have
326 occurred several times.

327 *G. longior* shells exhibited high proportion of shells with smooth surfaces, which could
328 suggest the presence of other components in the water that also intervened in the
329 corrosion of the shells. We propose that water currents containing suspension particles,
330 such as sand grains, grounded and eroded shell surfaces and edges. Moreover, shells
331 also exhibited a high proportion of rounded edges. Besides waves and tides that
332 produced shell abrasion, the factor of exposure time was implied here favoring worn
333 shell edges. *G. longior* shells may have been subjected to transport but also may have
334 rolled back and forth (Smith & Nelson 2003), oscillating on the water-sediment
335 interface. Despite the fact that the three samples exhibited high corrosion, rounding and
336 presence of *post-mortem* traces, they showed different taphonomic signatures. Sample
337 PD 2016 can be differentiated from PD 2018A and PD 2018B, primarily based on
338 fragmentation, rounding and internal and external cementation.

339 Shells from PD2016 showed higher fragmentation than shells from PD2018A and
340 PD2018B. Taking into account that this taphonomic attribute is related to mechanical
341 stress (Hollmann 1966; Brett & Baird 1986; Parsons & Brett 1991), water flow could be
342 a significant environmental factor. In terms of fragmentation, these currents could have
343 been accompanied by big particles such as shell fragments, which struck and broke *G.*
344 *longior* valves (Brett & Baird 1986; Parsons & Brett 1991). Therefore, during the
345 biostratinomic phase, the environment of Punta Delgado had been subjected to tides and
346 wave action contributing to the high fragmentation of shells which would have been
347 transported by more energetic episodes such as storms and led to the accumulation on
348 the beach ridge where PD2016 belong.

349 On the other hand, shells from PD2018A and PD2018B exhibited a similar
350 taphonomical profile between them characterized by low fragmentation, high rounding
351 and internal and external cementation. Their rounding edges and high abrasion suggest
352 that shells were oscillating on the water-sediment interface and were accumulated *post-*
353 *mortem* in the wave/tidal zone as a loose material similar to those from PD2016.
354 However, low fragmentation and high rates of rounding suggest that water currents
355 contain suspended particles, such as sand grains, ground and eroded shell surfaces and
356 edges but in a minor intensity or energy than PD2016 assemblage suffered. The high
357 rates of internal and external cementation on PD2018A and PD2018B shells indicate
358 that the water flow allowed the mobility of shells within the wave zone and/or tidal
359 zone, where their cementation would occur (Moresby 1835; Hanor 1978; Hopley 1986;
360 Vousdoukas *et al.* 2007). As other studies have shared, cementation could be achieved
361 under specific physical-chemical-microbial conditions in a tidal or immediately supra-

362 tidal environment depending on seawater temperatures, evaporation, mixing of seawater
363 with meteoric and groundwater, wetting and drying, microbiological activity and upon
364 the concentration of seawater CO_3^{-2} (Schmalz 1971; Molenaar & Venmans 1993;
365 Stoddart & Cann 1995; Turner 2005; Vousdoukas *et al.* 2007; Mauz *et al.* 2015).
366 Therefore, the bivalve death assemblages from the beach ridge where PD2018A and
367 PD2018B belong, detect a more favorable environment for carbonate precipitation than
368 the beach ridge where PD2016 belong.

369 Today, San Antonio Bay is subject to periodic storms with southeast winds and strong,
370 high waves that produce coastal erosion (Kokot *et al.* 2004). Furthermore, this bay
371 exhibits a hydraulic regimen determined by semi-diurnal tides, with a maximum spring
372 tide of 9.56 m (Aliotta *et al.* 2000; SHN 2018). Tide currents have maximum values
373 recorded at 2 m/sec (SHN 2018), which is a high-energy environment where intertidal
374 banks are subject to intense morphodynamic processes (Isla *et al.* 1995; Moreira *et al.*
375 2011). However, today the Punta Delgado site is not affected by storms or wave action,
376 and is actually a low-energy environment and a protected area due to its geomorphology
377 (Fucks *et al.* 2012; Kokot & Favier-Dubois 2017). Only extraordinary high tide can
378 reach the shore in Punta Delgado, leaving a backwash at 9.30 m, where the study site is
379 not affected by tidal flows (pers. observ.; Fig. 3.6). Also, this site is located in the
380 northern margin of the Punta Delgado spit bar, where the refraction of waves
381 propagating through the inlet channel generated these curvilinear beach ridges parallel
382 to the shoreline (see Fig. 1.2).

During the Holocene, beach ridges started to be accumulated on the Pleistocene spit bar of Punta Delgado. However, there were some differences in the preservation pattern of shells from adjacent beach ridges which would correspond to different history or taphonomic setting. When considering that both sampled beach ridges are located in an active coastal environment, inland beach ridges tend to be older than seaward beach ridges. Thus, the beach ridge where PD2018A and PD2018B were taken, would be older than the beach ridge where PD2016 was taken. The shells of PD2018A and PD2018B were subject to continuous, less intense water flow charged with smaller particles. Consequently, the valves resulted in longer time remaining in the taphonomically active zone. Longer time in a less intense hydrodynamic sediment-water interface, with other environmental factors, would favour higher shell cementation. On the other hand, shells from PD2016 were subject also to continuous but more intense or energetic water flow, such as wave action, and charged with bigger particles. Shells would remain in the TAZ for enough time to confer smooth edges and to be colonized by clionid sponges. However, environmental factors were not suitable for cementation for PD2016.

We propose that Punta Delgado is a Pleistocene spit bar with Holocene large deposits which exhibit extensive long-term time-averaging of mostly *G. longior* shells. This site is the product of a complex history of transport and reworking of materials (Kidwell 2013), in a Holocene environment affected mostly by spring tides. A previous study in San Antonio Bay, using a bivalve species as a target taxon, found that the taphonomic signature of the *E. purpurata* shells was also interpreted as a low-energy environment with varying intensity depending on the locality (Bayer *et al.* 2016). The transported

406 and reworked material of *E. purpurata* indicated an earlier deposition and, also, at least
407 one storm event (Bayer *et al.* 2016). Thus, considerable time-averaging was observed
408 in those associations from San Antonio Bay (especially in the eastern side, Punta
409 Villarino) (Fürsich and Aberhan, 1990; Kidwell, 1991; 2013). In our study, the western
410 side of San Antonio Bay, the taphonomical pattern of *G. longior* assemblages from both
411 beach ridges of Punta Delgado are characterized by the differences in shell rounding
412 and cementation corresponding to differences in the water flow intensity, coinciding
413 with Bayer *et al.* (2016) proposed studying *E. purpurata* as target species.

414 The intense water currents caused by sporadic storms and spring tides in Punta Delgado
415 could have produced mechanical reworking and selection of materials which have a
416 specific composition and mechanical resistance (Chave 1964; Cadée 1968; Bayer *et al.*
417 2016). The high concentrations of *G. longior* on the beach could be due to its very thick,
418 planar shape (López *et al.* 2008), as well as a cross lamellar microstructure that confers
419 higher mechanical strength (Rhoads & Lutz 1980; Bolmaro *et al.* 2006; Boretto *et al.*
420 2013). These characteristics allowed *G. longior* to persist over time and to withstand
421 transport and weather conditions in the swash zone (López *et al.* 2008). The high
422 mechanical resistance of *G. longior*, together with the high shell supply, could have
423 produced large deposits. However, other species whose shells have low mechanical
424 strength would not be found at all or would be found in low proportions. Therefore, *G.*
425 *longior*, a common warm-temperate species that is also abundant in marine Quaternary
426 deposits (Bayer *et al.* 2016) serves as a useful target taxa for future taphonomic
427 comparisons.

428 **CONCLUSIONS**

- *Glycymeris longior* valves from Holocene Punta Delgado deposits showed two taphonomic signatures, in terms of fragmentation, rounding and cementation differences.

- Shells from PD2018A and PD2018B were subject to continuous and low energy water flow. Those remained in a less-intensity hydrodynamic sediment-water interface that would favour high degree of cementation. Shells from PD2016 were subject also to continuous but more intense or energetic water flow. Those would remain in the taphonomically active zone for enough time to confer smooth edges and to be colonized by clionid sponges but not enough favourable for carbonate precipitation.

- The Punta Delgado site was interpreted as a protected area during the Holocene (last 4200 yrs.) similar to the modern one, but with differences in carbonate precipitation as the product of differences in water flow intensities.

- The high mechanical resistance of *G. longior* shells, together with the high shell supply, produced large deposits in Punta Delgado spit bar.

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747

Appendices

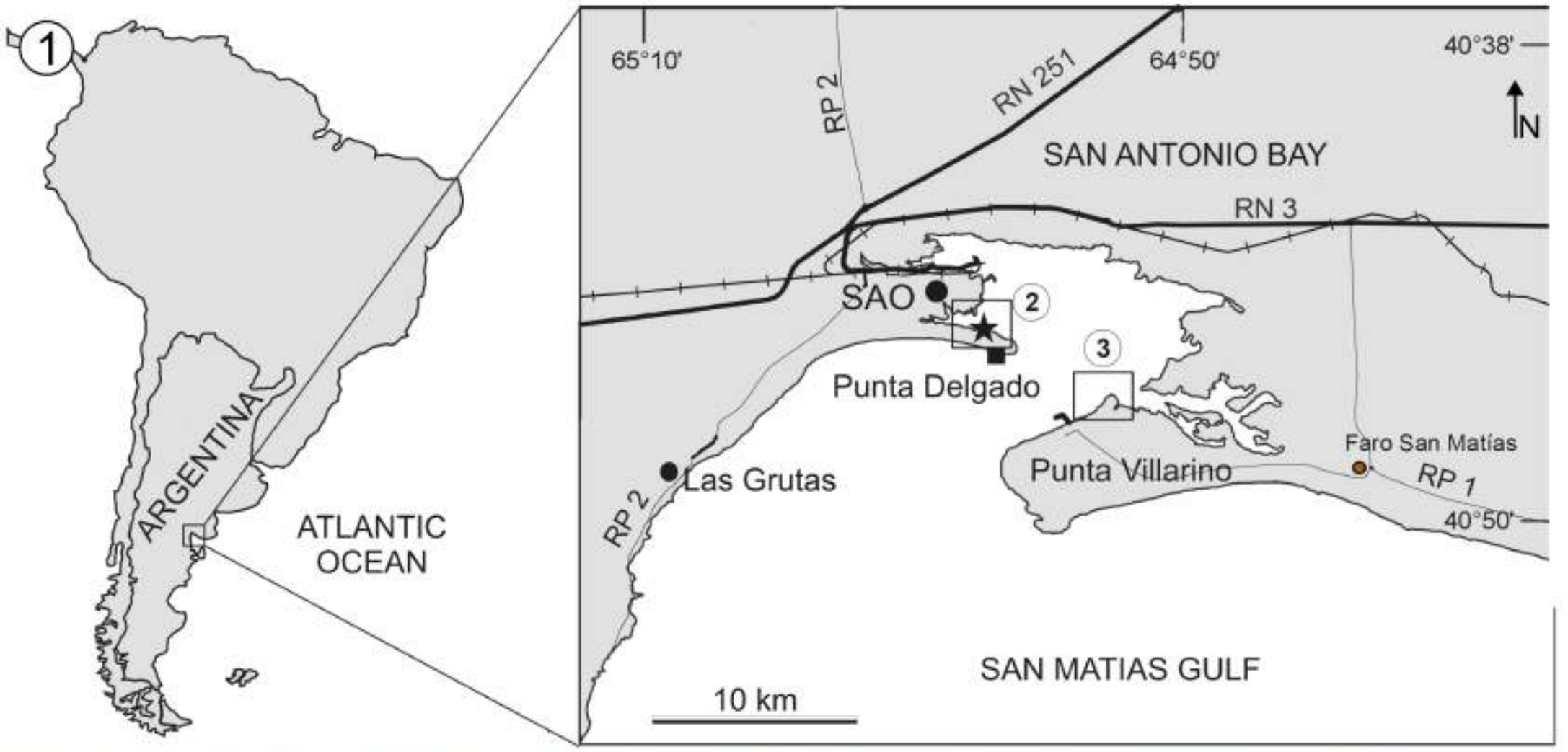
Figure captions

Figure 1. 1, location map of the study area showing the Punta Delgado deposits in the Punta Delgado spit bar, on the western side of San Antonio Bay, SMG (Argentina). **Star** points Punta Delgado samples, **dots** point San Antonio Oeste (SAO) and Las Grutas cities, and **square** points Alpat plant; **2-3 s**how mapped curvilinear and longitudinal beach ridges (yellow dotted line) at Punta Delgado spit bar (2) and Punta Perdices (3).

Figure 2. 1, contour map showing the location of the San Matias Gulf (SMG) semi-enclosed basin and the Salinas Trapalcó Laguna Curicó Lineament trend; **2,** geological map (from Martinez *et al.* 2001) of San Antonio Bay, SMG (Argentina); **3,** geomorphology of the San Antonio Bay (modified from Angulo *et al.* 1981) with samples location (star). Note that samples are located in Punta Delgado which corresponds to the western spit bar.

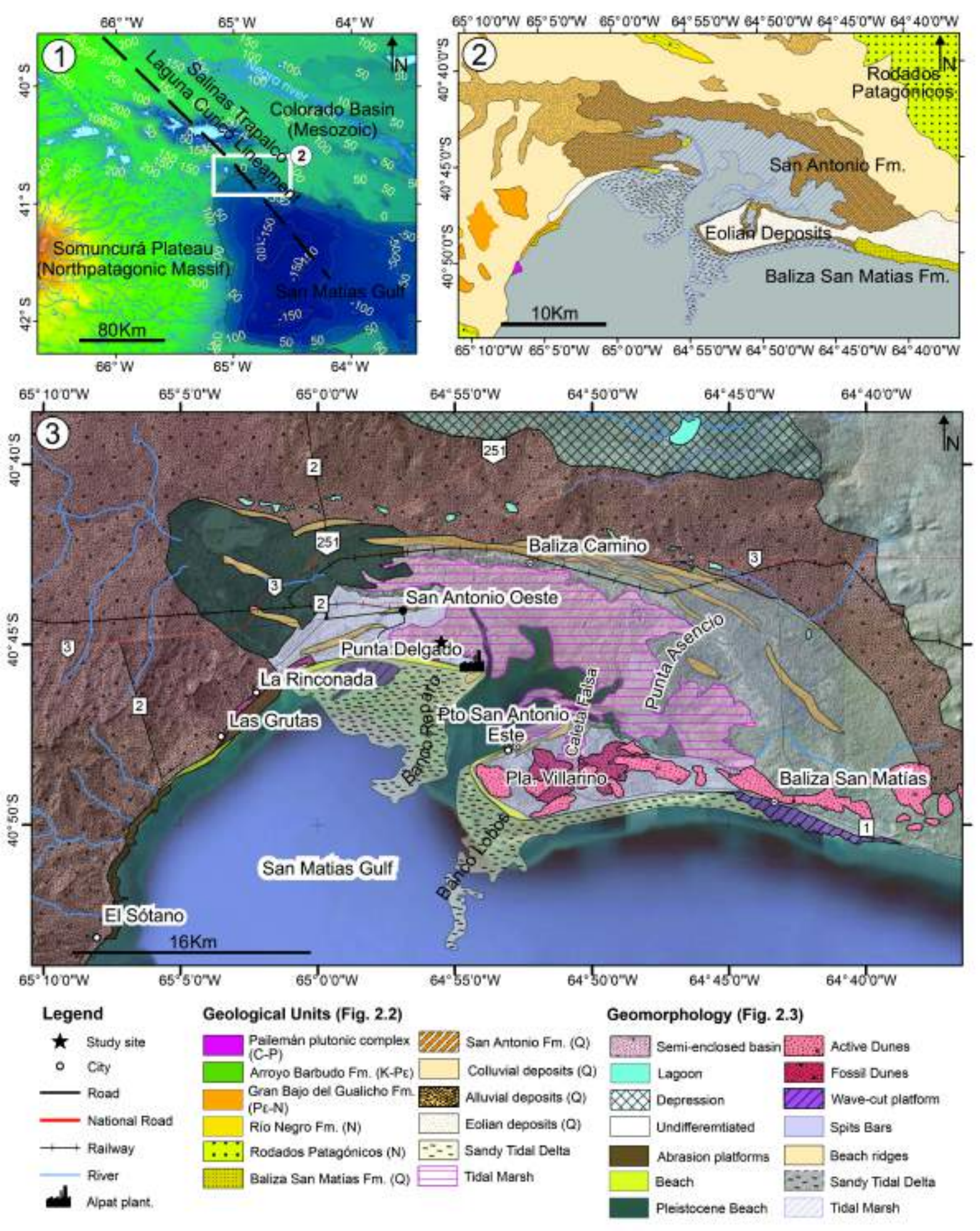
Figure 3. Field photographs of the study site. **1,** westwards view of San Antonio Bay at spring tide. Bay is completely flooded, star points sampling site (PD 2016); **2,** eastwards view of San Antonio Bay at spring tide. The dotted line points to the drift line that is located below the beach ridge; **3,** San Antonio Bay at low tide, northwards view from sampling point. The picture was taken standing on the sampling area; the beach ridge is the limit of spring tide; **4,** close up view of a beach ridge showing one shell assemblage dominated by *Glycymeris longior* valves; **5,** close up of the sampling site (PD 2016) in

771 the Punta Delgado deposit, see partial thickness of the deposits; **6,** sampling point detail,
772 densely packed. Scale bars = 20 cm.
773
774 **Figure 4.** Taphonomic attributes of *G. longior* valves. Fragmentation: 0, not fragmented
775 shell; 1, shell showing less than 30% of fragmentation; 2, shell showing more than 30%
776 of fragmentation. Rounded; No corroded (and no rounded); Corroded; Internal
777 cementation; External cementation; Post-mortem trace. Scale bars = 1 cm.
778
779 **Figure 5.** Non-metric multidimensional scaling (nMDS) illustrating Punta Delgado
780 shells and groups (samples) formed by taphonomic attributes on a two-dimensional
781 space.
782


1
ARGENTINA
ATLANTIC OCEAN
65°10′
64°50′
40°38′
40°50′
RP 2
RN 251
RN 3
RP 1
SAN ANTONIO BAY
SAO
2
3
Punta Delgado
Punta Villarino
Faro San Matías
Las Grutas
SAN MATIAS GULF
10 km
N


2
PD2016
PD2018A
PD2018B
Punta Delgado
Alpat Plant
616 m
N


3
Punta Perdices
Caleta Falsa
512 m
N


1
Salinas Grandes
Laguna Curacó
Lineament
Colorado Basin
(Mesozoic)
Somuncurá Plateau
(Northpatagonic Massif)
San Matias Gulf
80Km
2
Rodados
Patagónicos
San Antonio Fm.
Eolian Deposits
Baliza San Matias Fm.
10Km
3
Baliza Camino
San Antonio Oeste
Punta Delgado
La Rinconada
Las Grutas
Banco Reparo
Pto San Antonio
Este
Caleta Falsa
Punta Asencio
Pla. Villarino
Baliza San Matías
Banco Lobos
San Matias Gulf
El Sótano
16Km
Legend
Study site
City
Road
National Road
Railway
River
Alpat plant.
Geological Units (Fig. 2.2)
Pailemán plutonic complex (C-P)
Arroyo Barbudo Fm. (K-Pε)
Gran Bajo del Gualicho Fm. (Pε-N)
Río Negro Fm. (N)
Rodados Patagónicos (N)
Baliza San Matias Fm. (Q)
San Antonio Fm. (Q)
Colluvial deposits (Q)
Alluvial deposits (Q)
Eolian deposits (Q)
Sandy Tidal Delta
Tidal Marsh
Geomorphology (Fig. 2.3)
Semi-enclosed basin
Lagoon
Depression
Undifferemtiated
Abrasion platforms
Beach
Pleistocene Beach
Active Dunes
Fossil Dunes
Wave-cut platform
Spits Bars
Beach ridges
Sandy Tidal Delta
Tidal Marsh


1
N

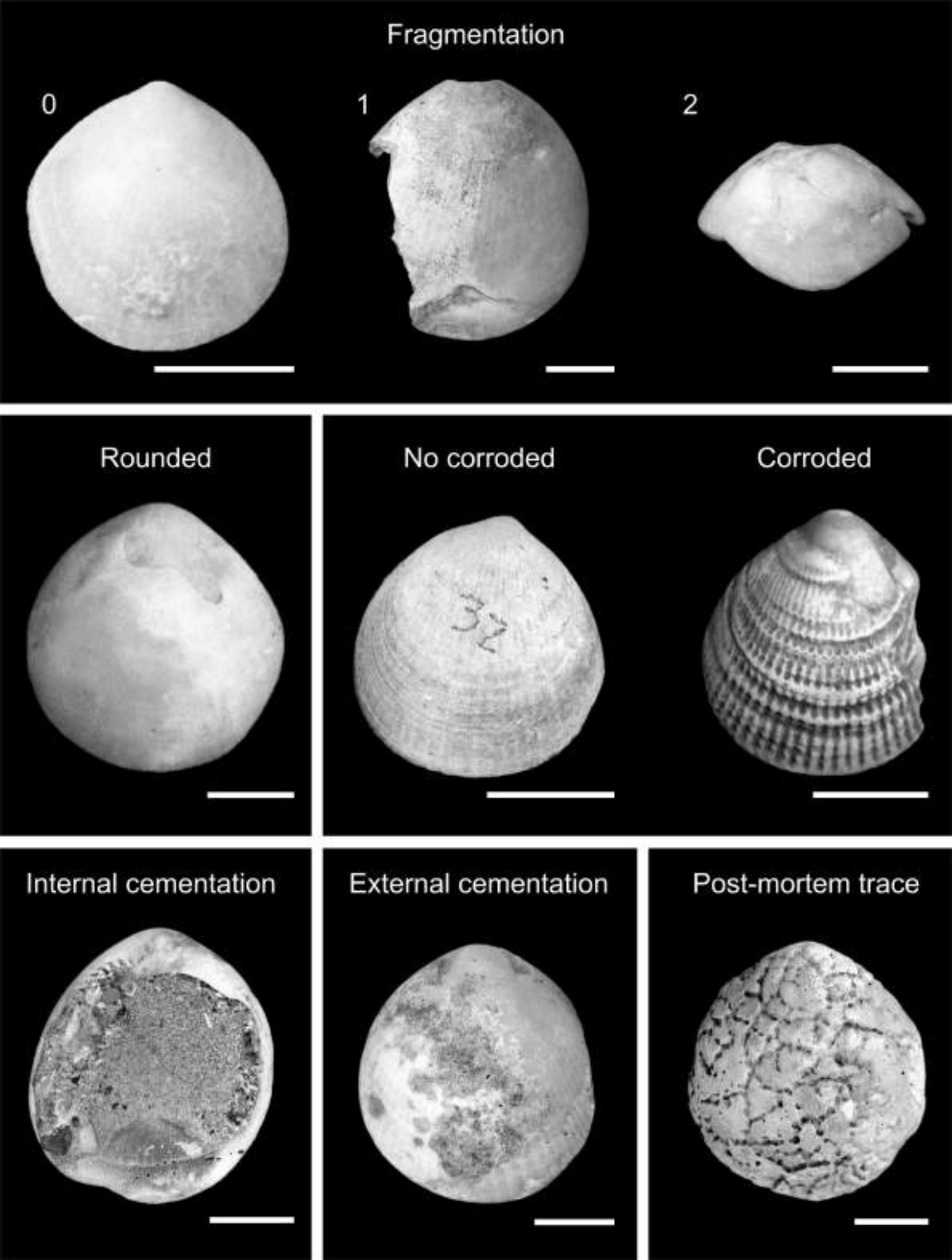

2
Alpat
N
drift line

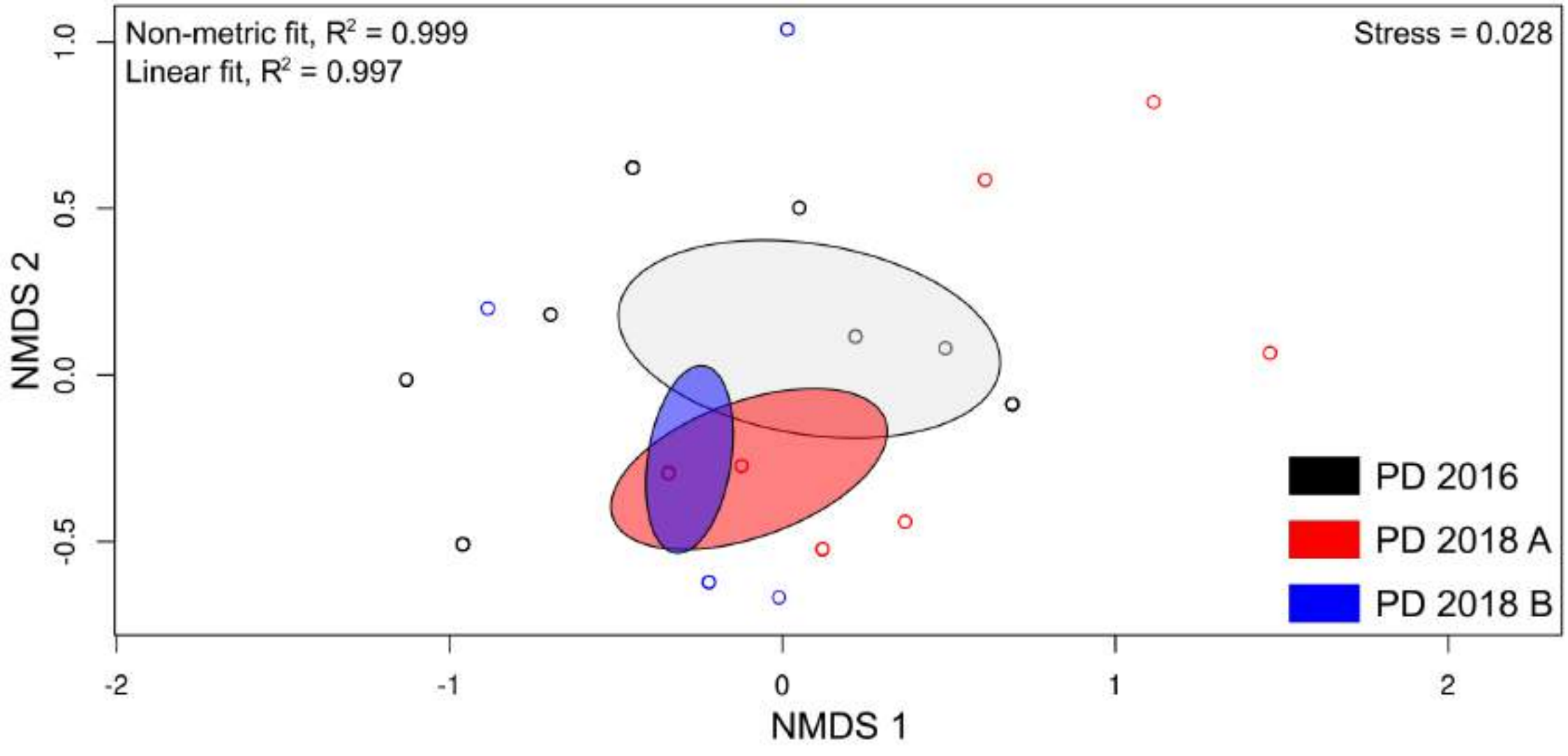

3
San Antonio Oeste
San Antonio Bay
N


4


5


6


Fragmentation
0
1
2
Rounded
No corroded
Corroded
Internal cementation
External cementation
Post-mortem trace


Non-metric fit, R^2 = 0.999
Linear fit, R^2 = 0.997
Stress = 0.028
NMDS 2
NMDS 1
1.0
0.5
0.0
-0.5
-2
-1
0
1
2
PD 2016
PD 2018 A
PD 2018 B

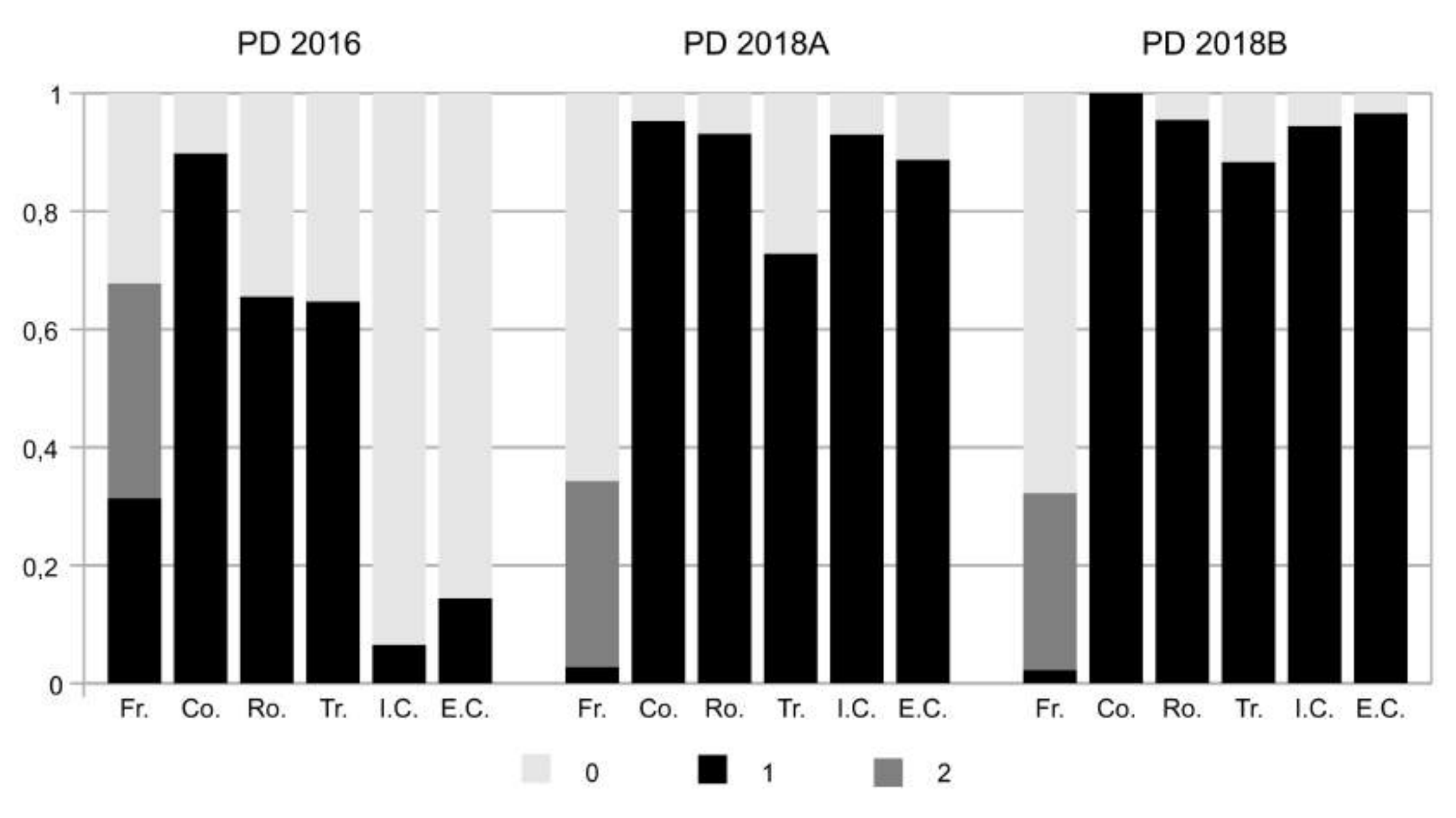

PD 2016
PD 2018A
PD 2018B
1
0,8
0,6
0,4
0,2
0
Fr.
Co.
Ro.
Tr.
I.C.
E.C.
0
1
2

TABLE 1. Percentages of taphonomic attributes per sample.

	Fragmentation		Corrosion		Roundness	*Post-mortem* traces	Internal Cementation	External Cementation
	0	1	0	1	1	1	1	1
PD 2016	5.93	94.07	10.17	89.83	64.41	64.69	6.50	14.41
PD 2018A	30.14	69.87	4.11	83.56	93.15	69.86	91.78	86.30
PD 2018B	14.61	86.51	0	100	96.63	76.40	94.38	95.51