

Topics in Geobiology 48

Sergio Martínez
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Actualistic Taphonomy in South America

 Springer

Topics in Geobiology

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Series Editors

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Preface

Taphonomy has certainly come a long way. Although the publication of the neologism coined by Efremov in 1940 is considered—not without reason—the foundational event of the discipline, it is also true that its basic concepts had been used since the dawn of Paleontology. Classic broad-spectrum books such as Darwin’s “On the Origin of Species” and early paleontological treatises as Zittel’s incorporated important sections on preservation.

Among the antecedents immediately before 1940, the scientific production of the *Aktuo-Paläontologie* school in Senckenberg am Meer under the direction of Rudolf Richter is of utmost importance. Posterior to 1940, taphonomical studies developed irregularly, being mostly considered subsidiary to paleoecological research, in times when Paleocology became a high profile discipline, especially from the 1960 decade until the mid-1980s.

A symbolic inflection point was the launching of *PALAIOS* in 1986, a journal representative of a new and influential generation, which emphasized the importance of obtaining new data through the study of patterns and processes of fossilization, instead of worrying about the loss of (biological) information. This revitalization of the discipline included the Actualistic Taphonomy branch, as was later named. This kind of approach has dealt with a wide range of organisms, and incorporated quantitative techniques that have broadened and deepened the investigations.

During the past years, Actualistic Taphonomy had a big boost in South America, especially in the so-called “southern cone” (Argentina, Brazil, Uruguay), as shown by numerous papers, books, talks, and theses. The state of the art in the region deserved a focused meeting in order to exchange experiences and to promote the development of the discipline into the future. This book is a consequence of the Workshop “Actualistic Taphonomy in South America”, that took place in Montevideo (Uruguay) during October 9–11, 2017, organized by the Invertebrate Paleontology & Ichnology Laboratory (Paleontology Department, Facultad de Ciencias, Universidad de la República). The book chapters show the amplitude of the actualistic taphonomic studies in South America. Subjects of study comprise plants, invertebrates, vertebrates, ichnites, and human artifacts (zooarcheological

and lithic), showing the diverse specializations of the authors. According to the nature and spirit of the event and book, the chapters exhibit different amplitude, in which the reader will find revision and original papers, new ideas, qualitative and quantitative approaches. Consequently, this book pretends to be as ample and diverse as our continent is.

Montevideo, Uruguay

Sergio Martínez
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Chapter 1

Taphonomy of Recent Bioclastic Deposits from the Southern Brazil Shelf: Stratigraphic Potential



Fernando Erthal and Matias do Nascimento Ritter

Abstract In the Southern Brazil Shelf (SBS), surface bioclastic concentrations are associated with putative paleo-shorelines formed where wave ravinement surfaces are probably present. From the late Last Glacial Maximum, the SBS can be considered a sediment-starved passive margin continental shelf, with its morphostructural development fairly known. There, fourteen molluscan shell samples from near shelf-break deposits (“distal shell-rich”), eleven from proximal, low depth bioclastic deposits (“proximal shell-rich”) and ten samples from sandy substrate (“shell-poor”) were evaluated for taphonomic damage accordingly to updated protocols. Multivariate statistical analysis showed significant differences between the three groups of shelly samples. Low-intensity damage states (such as natural bright and ornamentation) dominate samples from the distal shell-rich deposit, whereas the inverse occurs in the proximal deposit (samples from the shell-poor locations present an intermediate damage pattern). This pattern is consistent either with onlap/toplap and backlap shell bed formation, according to characteristics determined in the literature. The condition of these three areas may reflect degrees of exposure at the taphonomically-active zone, the magnitude of time averaging and duration of shell accumulation, and even the lack of shelf accommodation space, which in turn is related to glacioeustatic sea-level oscillations.

Keywords Time-averaging · Stratigraphic paleobiology · Coquina · Shell preservation · Onlap deposits

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1.1 Conceptual Background

In the marine realm, besides from storm deposits or other allogenic processes, shell beds frequently develop in stratigraphically predictable areas through a combination of a series of sedimentary factors (Brett 1995; Kidwell 1989, 1991). Whereas the sedimentological and stratigraphic significance of fossil concentrations is well recognized (e.g., Kidwell 1989; Patzkowsky and Holland 2012), these have not commonly been used for ecological studies because of obvious issues of temporal and spatial averaging. However, recent works have suggested that shell beds can accurately record broad-scale ecological changes through geologic time (Li and Droser 1999; Kidwell 2013). Transgressive shell beds, with complex internal microstratigraphy (*sensu* Kidwell 1991), are common in Plio-Pleistocene shallow marine sedimentary cycles around the world (some examples include Abbot 1997; Kondo et al. 1998; Kidwell 1989; Fürsich and Oschmann 1993; Fürsich and Pandey 2003; Simões and Kowalewski 1998). Although cycles of coastal retrogradation and regression may punctuate transgressions, bioclastic deposits within the TST context probably encompass a high degree of time-averaging (Kidwell 1989; Fürsich and Pandey 2003; Scarponi et al. 2013). Good estimates and direct measures of the time enclosed within shell deposits are available for a variety of modern marine depositional settings (Krause et al. 2010; Scarponi et al. 2013; Kidwell 2013; Dexter et al. 2014; Dominguez et al. 2016; Ritter et al. 2017).

Naturally occurring bioclastic death assemblages are useful in determining the environmental control on the style of post-mortem damage to skeletal hard parts (Tomašových and Zuschin 2009; Parsons-Hubbard et al. 2011). Marine molluscan assemblages are likely to be ecologically mixed in composition and have taphonomically complex histories, because of shallowing and deepening cycles and the continuous shallow-water erosional reworking (Kidwell 1991). Intrinsic properties such as the mineralogy of carbonatic bioclasts (proportion of aragonite, high-Mg calcite, and low-Mg), may modulate the rate of taphonomic loss (Glover and Kidwell 1993). The taphonomic patterns of present-day developing deposits are well documented, especially for tropical marine areas. Hendy et al. (2006) described the taphonomic properties of several shell-beds from Miocene-Pliocene deposits of New Zealand under a sequence stratigraphy framework. They emphasized that closer attention should be paid to the taphonomic condition of shells within bioclastic concentrations, to refine environmental and stratigraphic interpretation. In this contribution, the naturally-occurring mollusk death assemblages from the Southern Brazil Shelf are considered a potential analogous for transgressive deposits preserved in the fossil record. The aim is to test if the damage profile of mollusk shells from several areas of shell accumulation allows predicting the properties of shell beds in similar transgressive system tracts from the deep-time fossil record.

1.2 Study Area

Despite considerable clastic contribution by the Plata River, the Southern Brazil Shelf (SBS, roughly within latitudes 27°S and 34°S) can be presently characterized as a sediment-starved passive margin continental shelf (Corrêa 1996). Deposition of a large amount of post-rift, primarily clastic sediment produced a wide (100–200 km), shallow (100–140 m), and gently sloping (0.03–0.08°) continental shelf (Dillenburg and Barboza 2014; Weschenfelder et al. 2014). Sandy sediments dominate the adjacent continental shelf out to a water depth of circa 60 m while muddy sediments predominate in areas of deeper water (Corrêa 1996; Dillenburg and Barboza 2014). In the southern area, sand bodies, sand waves and elongated bioclastic deposits (between isobaths of 10 and 50 m) interrupt the usually smooth morphology (Figueiredo 1975; Villwock et al. 1986; Corrêa 1996).

The present physiography of the coastal plain and shelf is mainly the result of Quaternary high-frequency (4th order to 5th order), glacioeustatic sea level changes, that affected the sedimentary systems along the coast. The post-glacial sea-level history of this area extends back circa 15.5 kyr ago when the sea-level was 120–130 m below the present position (Villwock et al. 1986; Corrêa 1996). After that time, the sea-level rose at an average rate of 1.2 cm/yr, beginning after the onset of the Postglacial Marine Transgression (PMT). Sea level stabilized at 9 kyr (between depths of 32 and 45 m) and 8 kyr (between depths of 20 and 25 m; Corrêa 1996; Nagai et al. 2014). Sparse data exists on the sea-level behavior during middle to late Holocene, and sea-level curves for areas to the north indicate that at the culmination of the PMT, the sea-level was 1–3 m (perhaps up to 4 m) above its present level, which occurred between 4.1 and 2.7 kyrs ago (Corrêa 1996; Angulo et al. 2006; Martínez and Rojas 2013).

1.3 Materials and Methods

A sampling of top marine sediment, rich in molluscan dead remains was conducted during several oceanographic expeditions promoted by Brazil Navy in cooperation with universities (Kowsmann et al. 1977; Figueiredo and Tessler 2004). Given their assumed reworked nature (Figueiredo 1975; Corrêa 1996), shell samples from 35 bottom-level locations (Fig. 1.1) can be evaluated in terms of developing condensed deposits within a (fourth to fifth order) transgressive sequence, such as the apparent stage of SBS. At least 150 shells or fragments of multiple species of bivalves larger than 4 mm by location were inspected for taphonomic damage, following standard taphonomic protocols such as the presented in Ritter et al. (2019). Briefly, we quantified the intensity of taphonomic variables considering damage states varying from 0 (zero, no damage present) and 1 (damage present). Based on location and sediment type, samples were grouped into three regions or so-called provinces: one proximal, with high carbonate content (>50%) and low depths (<60 m); one distal, with high

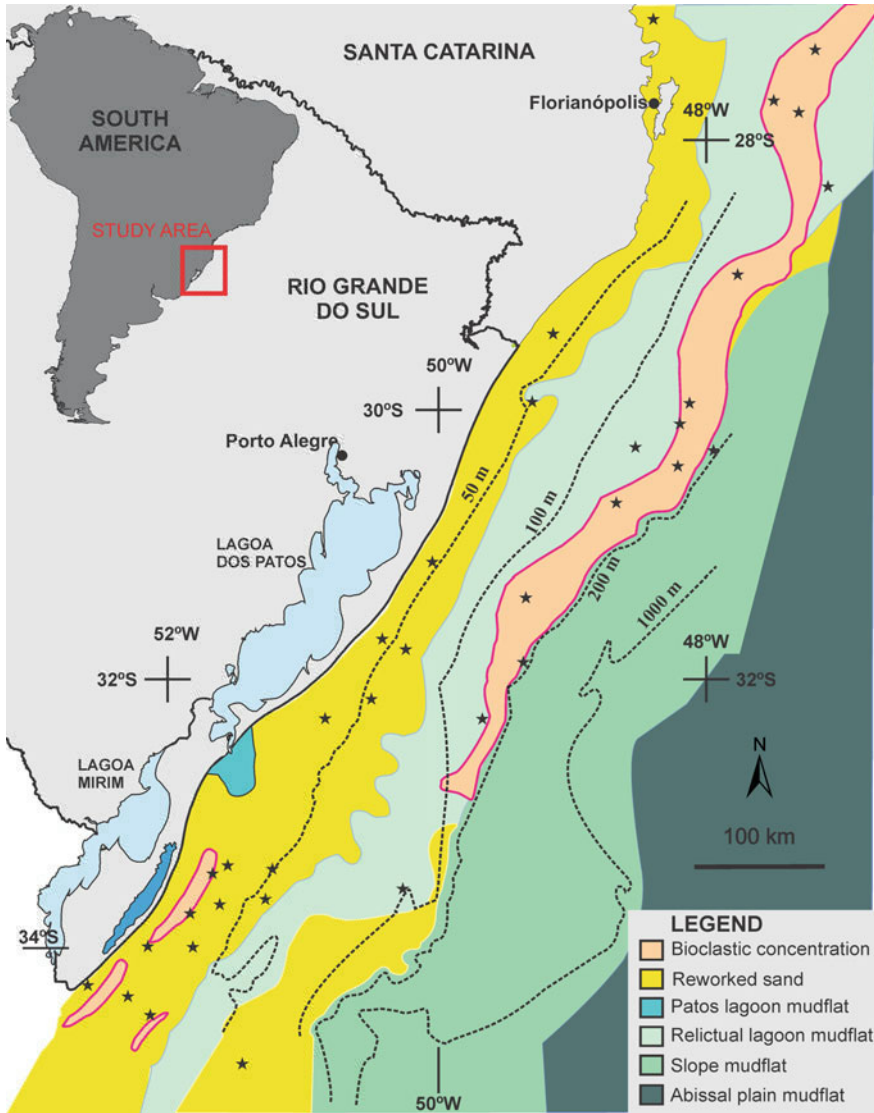


Fig. 1.1 Location of the study area and sampling sites, with indication of main geomorphological and sedimentary features (map modified from Figueiredo 1975; Vicalvi 1977; Kowsmann and Costa 1979; Kowsmann et al. 1977; Villwock and Tomazelli 1995; Corrêa 1996; Tomazelli and Vilwock 2000; Corrêa et al. 2014; Dillenburg and Barboza 2014; Weschenfelder et al. 2014)

carbonate content ($>50\%$) and great depth (>100 m); and a third area including very low carbonate ($\ll 50\%$) and high sand contents.

Non-metrical multidimensional scaling (NMDS) was used to visualize the distribution of sampling units accordingly to their taphonomic profile. To search for differences in the taphonomic profiled between sedimentary provinces (proximal and distal shell-rich, and sandy shell-poor) and depth ranges (shallow: less than 100 m; deep: more than 100 m), we used multivariate analysis of variance with permutation (PERMANOVA; Anderson 2001). The relationship between taphonomic profile and sediment grain-size and composition (environmental variables) was explored using Constrained Analysis of Proximities (CAP, also known as distance-based Redundancy Analysis; Legendre and Legendre 2012). NMDS, PERMANOVA, and CAP were conducted based on Manhattan distance, which is better suited for taphonomic data (Tomašových and Zuschin 2009). All statistical analysis and graphics generation were performed using statistical software R (R Development Core 2018).

1.4 Results

The multivariate analysis evaluates the total variation present in the data at one time, allowing discriminating bioclastic provinces in the SBS, with potentially better interpretations. Damage profiles within shell-rich and shell-poor provinces are strongly variable. The dispersion of sampling units from SBS according to the variation in their damage condition is shown in Fig. 1.2. The three sampling areas (proximal and distal shell-rich and sandy shell-poor) showed significantly different taphonomic profile, according to PERMANOVA (Table 1.1). This difference persists even when separating the damage profile into the biological and physical origin and color alteration, and the taphonomic variation follows the depth gradient, as samples shallower than 100 m are significantly different from samples deeper than 100 m (Table 1.1). A neat variation of the taphonomic profile according the sedimentary carbonate and gravel content is observed in the NMDS (Fig. 1.2).

Table 1.1 Results of PERMANOVA examining the multivariate difference between three groups of sampling units (provinces) considering presence of shell-rich and shell-poor areas and groups of sampling sites according to depth (shallow × deep samples)

	F value	P value
<i>Province</i>		
Total damage profile	5.0211	<0.01
Biological damage	4.2356	<0.01
Physical damage	7.5111	<0.01
Color alteration	3.1103	<0.01
<i>Depth</i>		
Total damage profile	7.7297	<0.01
Biological damage	7.2194	<0.01
Physical damage	13.308	<0.01
Color alteration	2.7113	>0.05

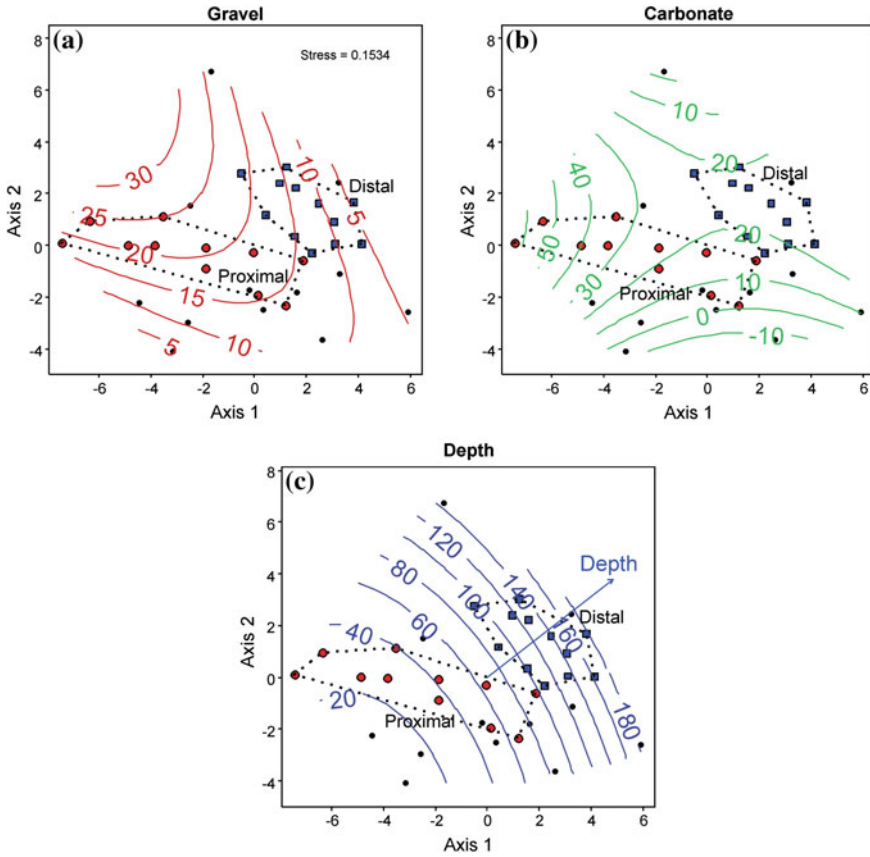


Fig. 1.2 NMDS (based in Manhattan distance) showing dispersion of the studied mollusk samples from the SBS based on the taphonomic profile. Function ordisurf (in the “vegan” package; Oksanen et al. 2019) allowed fitting thin plate splines (gradients) showing proportion of sedimentary carbonate (a), gravel content (b) and depth gradient (c). Dotted hulls show sites contained within the proximal and distal shell-rich zones, which form significantly different groups accordingly to PERMANOVA (Squares = distal shell-rich province; Circles = proximal shell-rich province; Smaller dots = dispersed shell-poor samples). The proportion of damage for each taphonomic variable at each sampling site was standardized (scaling to zero mean and unit variance) and normalized (making the sum of squares equal to one) prior to analysis

Constrained analysis of proximities based on Manhattan distance of taphonomic data shows that the environmental factors explain almost 35% of the entire taphonomic profile, with 73% of variation indicated by Canonical Axis 1 (53.2%) and Canonical Axis 2 (19.7%) (Fig. 1.3a). In the proximal shell-rich province, the damage is mainly controlled by the increase in carbonate and gravel content of the sediment, and secondarily by a decrease in depth and mud (clay + silt) (Fig. 1.3a). Figure 1.3b–q show the variation of all taphonomic conditions measures in the samples across the SBS. Most biologically-originated damages are found in the distal shell-rich

province, where depth and gravel and sand proportions affected most (Fig. 1.3b–g). Depth and sand content, which are inversely proportional, and the variation in gravel and mud content appears to influence the damage pattern in the proximal shell-rich samples, an area with the strongest signal for physical origin damage (Fig. 1.3h–q). It is noteworthy that a small group of taphonomic signatures (drilling, large pits, natural ornamentation and bright) appears to influence more the distal shell-rich area. Based on the constrained analysis of color alteration and sedimentary factors, the shell-rich provinces overlap (Fig. 1.3d), despite being significantly different (Table 1.1).

1.5 Discussion

1.5.1 Taphonomic Profile of Bioclastic Deposits from SBS

Although several damage states lump at the origin of canonical axes, key variables relate to increases and/or decreases in the measured sedimentary variables. The clustering of low-damage (near pristine) signatures such as natural ornamentation and natural bright, which occurs preferentially in the distal shell-rich province, may attest the lower influence of high-energy environmental conditions in that region. This pattern was also found in comparable Cenozoic depositional settings, and may reflect the intense reworking caused by the action of waves and currents (Kidwell 1986; Fürsich and Oschmann 1993; Kondo et al. 1998; Hendy et al. 2006). Nevertheless, damage reflecting high-energy environments, such as ornamentation loss, secondary luster, and accentuated ornamentation are common in SBS. Bioclastic remains at the proximal province might have faced harsh environmental conditions, during a longer time span, consistent with the reworked nature of the SBS deposits.

Physically originated signatures discriminate the shell-rich provinces better, implying that transport by waves and currents act coordinately over sedimentary sequences and damage condition of bioclastic deposits. Sediment bypassing and starvation (Kidwell 1991) can often lead to intense mechanical wearing of shells, as well as colonization by bioeroding and encrusting organisms (Young and Nelson 1985; Cutler and Flessa 1995). The intense bioerosion found in all sites and provinces of SBS may be due to the constant exposure of shells to the sediment-water interface, caused either by the low clastic sedimentation or little accommodation space in the studied area during post-LGM times.

A mild bathymetric pattern of taphonomic alteration is present, based on the results of NMDS. Attritional-related signatures are more frequent in the proximal (shallow) shell-rich province while dissolution-related signatures prevail in the distal shell-rich area (Figs. 1.2 and 1.3). It means that some bathymetric conditioning might have induced the observed taphonomic profile of shell samples from the SBS. On the other hand, many thousands of years must separate the genesis of the two provinces, regardless of whether they relate to early episodes of shoreline stabilization

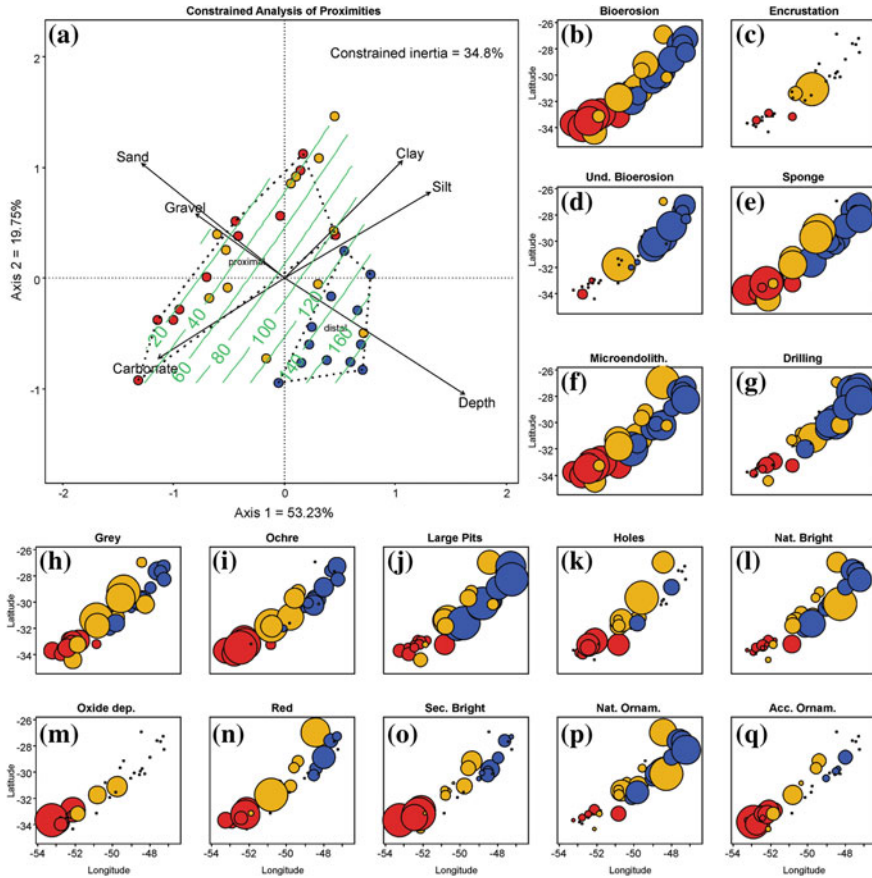


Fig. 1.3 Constrained Analysis of Proximities of the shelly samples from SBS. **a** Entire taphonomic profile. **b** Damage of biological origin. **c** Damage of physical origin. **d** Color alteration. Environmental factors are in capital letters when significant after forward selection, and taphonomic signatures are in italics. Sampling units were omitted from the dispersion plot for clarity. The intensity of distinctive taphonomic variables through sampling units are displayed in graphs (**b–p**). Abbreviations are: Und. Bioerosion = Undetermined Bioerosion, Microendolith. = Microendolithic Traces, Nat. Bright = Natural Bright, Oxide dep. = Oxide deposits (crusts), Sec. Bright = Secondary Bright, Nat. Ornam. = Natural Ornamentation, Acc. Ornam. = Accentuated Ornamentation. Gray, Ochre and Red refers to color alteration (secondary colors acquired by the shells)

or not. Ritter et al. (2017, 2018) have shown that the age-variation of these death-assemblages can reach three-order of magnitude.

The bioclasts in the shell-rich areas might have been affected by abiotic and biotic factors taking place during significant shifts in environmental conditions, from below storm wave base level to nearshore and foreshore (Fig. 1.4), and probably under lagoon influence (Ritter et al. 2013). In addition, the longer the shells remain exposed in the upper limit of the benthic TAZ, the stronger will be the environmental

imprint on the taphonomic pattern preserved (Davies et al. 1989; Olszewski 2004; Smith and Nelson 2003; Parsons-Hubbard et al. 2011). Although the prevalence of biological damage in the distal province, and physical damage characterizing better the proximal province, the biologically originated signatures are also known to relate to specific environmental settings or conditions (Fürsich and Oschmann 1993; Lescinsky et al. 2002). The color alteration in bioclastic remains associated with the type of sedimentary geochemical properties, including but not limited to inhibiting factors such as sedimentary iron (e.g., Cai et al. 2006; Best et al. 2007; Powell et al. 2011). The color of shells altered to red hues (Fig. 1.3) was implied with subaerial exposure of bioclastic remains, with precipitation of reduced iron and manganese (Anjos-Zerfass et al. 2008; Corrêa et al. 2008). The effect of intrinsic factors such as species composition and shell mineralogy and microstructure on the relation between damage profile and depositional properties in the SBS is an interesting issue to detail in a future work.

1.5.2 Influence of Sedimentary Regime and Discontinuity Surfaces

Condensed deposits of all types are important and complex repositories of paleoecological and taphonomic data. Densely fossiliferous coquinas mark the base of marine depositional sequences: each shell deposit onlaps erosional (subaerial) disconformities (Kidwell 1991; Hendy et al. 2006), and are traceable over large areas (tens to hundreds of km²). That is the case of assemblages examined by Kidwell (1989; see also Kondo et al. 1998), including those presently found in SBS (Figs. 1.1 and 1.4). The ratio between sedimentation and erosion rates controls most of the taphonomic signatures observed in molluscan assemblages (Kidwell 1986, 1991; Tomašových et al. 2006). Whereas low sedimentation and reworking favor abrasion (as seen in the proximal area; Fig. 1.3), the winnowing of sediment enhances bioerosion.

Shell beds are dense (bioclast supported) concentrations of shelly fossils. It is a synonym of coquinas, lumachellas, shell gravels and bioclastic calcirudites, which may form transgressive lags, where shell supply is abundant, detrital sediment supply is low, in areas with significant sediment bypass or even lack of accommodation space in nearshore environments (Kidwell 1989, 1991). All these sedimentary features may be inferable from the bioclastic deposits present in the SBS. Despite low-to-null clastic supply in SBS, shell deposits may not be as dense or voluminous in this area when compared to other Quaternary deposits around the world. The estimated thickness for the shell deposits shown in Figs. 1.1 and 1.4 may vary from little more than 5 cm to 2.5 m (Figueiredo 1975). Emerged shell concentrations in the coastal plain of Southern Brazil reach thickness up to 6 m (Dillenburg and Barboza 2014). That bioclastic facies is highly reworked, reflecting high-energy environments (Kowsmann et al. 1977).

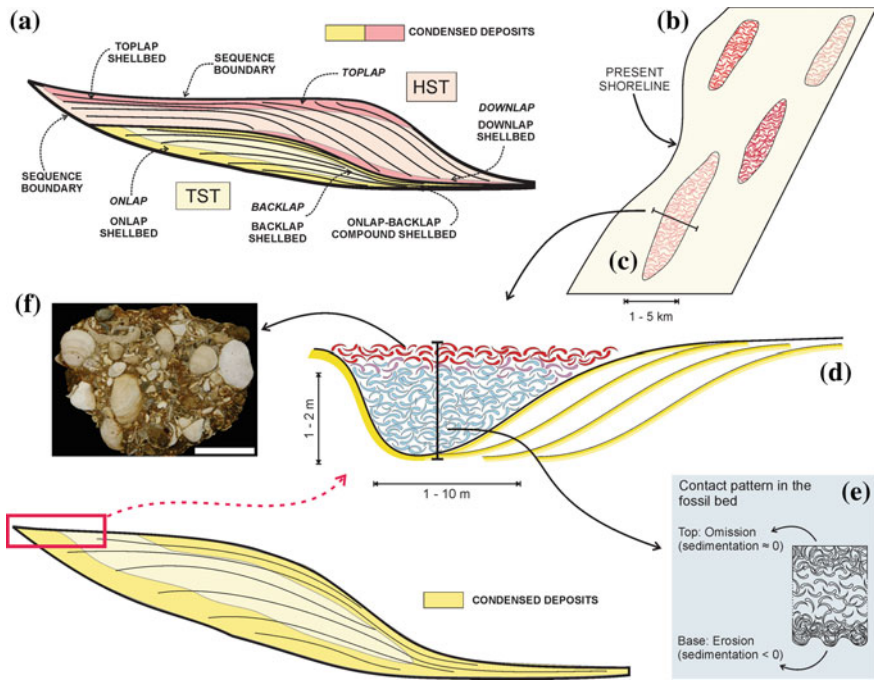


Fig. 1.4 Summary of the possible nature of developing onlap and backlap condensed deposits present in the SBS. **a** Generalized stratigraphic architecture showing transgressive and high-stand system tracts. **b** Generalized map and morphology of bioclastic bodies **c** in proximal continental shelf. **d** Hypothetical cross-cut of a single bioclastic deposit. **e** Contact pattern of the bioclastic deposit, based mostly upon classification of Kidwell (1985). **f** Example of a coquina found in the nearshore area of SBS, that is probably reworked from the top of an underwater bioclastic body (scale bar = 6 cm). Based mostly upon this and previously published work by Kidwell (1991), Fürsich and Oschmann (1993), Corrêa (1996), Fürsich and Pandey (2003), Hendy et al. (2006), Dillenburg and Barboza (2014), Weschenfelder et al. (2014)

In shallow marine accumulations, shell beds usually develop associated with changes in net sedimentation involving rates of deposition, omission (bypass) and erosion (Kidwell 1989, 1991). The degree of alteration of bioclasts may be consistently variable according to the sedimentary regime, although the sedimentation rate and shell input determine the relative exposure time of bioclasts at the sediment-water interface (Speyer and Brett 1986; Fürsich and Oschmann 1993; Smith and Nelson 2003; Tomašových and Zuschin 2009; Parsons-Hubbard et al. 2011).

The importance of contact-based discontinuities increases as they can reflect boundary surfaces used in sequence stratigraphy, especially where no other sedimentological or paleontological evidence can be determined (Courville and Collin 2002). Bioclastic lithosomes may develop above wave ravinement surface (or transgressive surface) in low gradient shelf, where sedimentation rate is low. Figure 1.4 explores a possible scenario for the formation of bioclastic-rich deposits under the

framework of sequence stratigraphy. Wave ravinement, at the base of a transgressive system tract, together with low sediment supply creates small valleys. This is the place of formation of onlap shell beds, where reworked shells of marine mollusks are deployed. While the entire bioclastic body probably encompasses intense time-averaging and a complex taphonomic pattern, the topmost shell layers probably reflect much of present-day environmental conditions. Marine benthos can colonize transgressive shell lags, creating taphonomically complex assemblages of potentially non-coeval fossils. Also, changes in sedimentation rate may produce discontinuity surfaces necessary for the recognition of stratigraphic sequences.

The overall result is that the type and pattern of damage present in marine (and coastal/transitional) assemblages offers a valuable information for the interpretative power of sequence stratigraphy (Brett 1995, 1998; Fürsich and Pandey 2003; Hendy et al. 2006). Transgressive deposits are relatively easy to trace in outcrop and seismic logs, for they are frequently bounded by erosive or omission surfaces (Cattaneo and Steel 2003; Catuneanu et al. 2011; Hendy et al. 2006). Moreover, transgressive system tracts typically preserve mixed and within-habitat transported assemblages (Zecchin and Catuneanu 2013), reflecting high-energy environments with variable degrees of inferred time-averaging and species richness, however (Fürsich and Pandey 2003). Therefore, transgressive fossil deposits (i.e., transgressive lags, but especially condensed onlap deposits) hardly represent paleocommunities.

1.5.3 Exposure Time of Bioclasts in Sediment-Water Interface

Combined sedimentological and taphonomic features from shell-rich deposits in the context of transgressive system tracts reveal that bioclasts persisted on the seafloor for a considerably long time, with intense post-mortem alteration prior to final burial (Kidwell 1989; Fürsich and Oschmann 1993; Abbott 1997; Abbott et al. 2005; Cantalamessa et al. 2005; Hendy et al. 2006). Skeletons included in those shell beds may be derived either from inhumation of indigenous living mollusks, previously buried and erosionally exhumed fossils or from shells transported from immediately adjacent, coeval environments, resulting in spatial mixing and remaniés (sensu Craig and Hallam 1963). Therefore, the fauna composition in those particular settings (such as the shell-rich provinces in SBS; Figs. 1.1 and 1.4) does not reflect the previous productivity history in the area. However, the topmost shell constituents may reflect the later environmental conditions, depending on the ultimate rate of sedimentation. Direct age dating of bioclastic material coupled to damage state discrimination indicated that at least two distinctive assemblages of taphonomically-altered remains are present in the SBS, with a clear shallow vs. deep patterning (Ritter et al. 2018).

Most actualistic studies conducted at facies-level scale found no general environmental trend that could be applied for fossil interpretation (Parsons-Hubbard et al. 2011; Powell et al. 2012). Those events occurred during Late Pleistocene-Early

Holocene (Ritter et al. 2017), although most of the shells are recent (97% younger than 6 ka). The result is a taphonomically altered sum of all those events and is thought to separate each of those processes. Environmental factors depending on depth may affect both the duration of bioclastic accumulation and the taphonomic profile of bioclasts (Ritter et al. 2018). Postmortem alteration is, by turn, a function of both exposure time (to the sediment-water interface) and the rate of bioclast production. Under low sedimentation rates, shells accumulate at or just below the SWI, with long exposure periods to post-mortem processes. Therefore, a positive correlation between shelliness and taphonomic alteration is predictable (Kidwell 1986; Fürsich and Aberhan 1990; Olszewski 2004), a pattern also observed in this study.

Caution is needed to understand the variety of circumstances involved in the rate of shell production and destruction, and some shelly deposits are better suited for paleoecological studies than others (Kidwell 1986, 1991). Condensed deposits may be taphonomically irregular, both within a single deposit and between deposits in a single basin, for shells may suffer countless cycles of burial and exhumation during periods of significant environmental change (e.g., distal vs. proximal shell-rich deposits in SBS; Fig. 1.4; Davies et al. 1989; Kidwell 1991).

1.6 Final Remarks

Several fossil concentrations preserve strongly biased ecological and environmental information, sometimes impairing further paleobiological reconstruction. On the other hand, the formation and preservation of a shell bed may reveal the intenser effect of environmental data than the actual fossils it contains. It is not well known whether rates of shell production in nearshore environments of Southern Brazil Shelf are high; therefore, shells may be considerably old, despite high rates of destruction in SWI. There is no common-sense in using damage state as an (even indirect) indicator for time-averaging (e.g., Ritter et al. 2017, 2018) since most taphonomic features become highly modified during burial and early diagenesis. On the other hand, different hard parts degrade at different rates. The cumulative—time averaged assemblages—may not represent the average environmental condition that prevailed during the duration of its formation.

The low present-day sedimentation in the Southern Brazil Shelf, allied to any rate of hard part productivity enabled the formation of highly time-averaged bioclastic deposits (low productivity + low sedimentation = high time averaging), with the formation of *remaniés* (bioclastic material with complex depositional and taphonomic histories, accumulated during wide time intervals and possibly subject to several burial and re-exposure cycles). Shells with highly variable taphonomic conditions compose the distal and proximal shelly provinces, implying intense and prolonged exposure to harmful agents in the taphonomically active zone. Despite this variability in postmortem alteration, the damage profile of these bioclastic bodies reflects the history of sea level variations occurred in the area, and this pattern can be applied to

fossil concentrations present in the older deposits, allowing better interpretation of marine sedimentary sequences.

The proposition here is that the bioclastic deposits from shell-rich areas in SBS formed during early, proximal transgressive system tracts (regions of onlap), underlain by wave ravinement surfaces. It would imply that the lower boundary of such deposits is erosive, and the upper limit of those deposits consists of an omission to erosive surfaces. The better preservation state of shells from the distal province are consistent with the taphonomic pattern exhibited by fossils deposited at regions of apparent truncation (backlap, or condensed section).

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