Chapter 2
Taphonomy

Abstract Taphonomy is the "*science of the laws of burial*" (Efremov 1940); it involves the transition of animal remains from the biosphere to the lithosphere. In this chapter we refer to various taphonomic attributes (e.g., fragmentation and abrasion, among others) by looking at examples in different environments and different taxa; and we explain the advances made in taphonomy by the working group.

Keywords Southern South America · Quaternary · Pleistocene · Holocene · Mollusca · Taphonomy · Taphonomic attributes · Taphonomic grades · Fragmentation · Dissolution

2.1 Taphonomy as a Cross-Disciplinary Branch

Taphonomy is the "*science of the laws of burial*" (Efremov 1940), "*a branch of paleontology, and almost a branch of ecology*" (Gordillo 2011), and–as it involves the transition of animal remains from the biosphere to the lithosphere–taphonomy is also the study of the death and decay of organisms, including the process of fossilization.

The terms "authochthonous", "parautochthonous" and "allochthonous" proposed by Kidwell et al. (1986) are currently used by many authors to describe the nature of preserved mollusk assemblages. If they are transported, and therefore indicative of the environments in which they finally ended up, they are allochthonous assemblages. If the preserved shells are recovered in situ, and therefore record the environment in which they lived, they are authochtonous assemblages. Finally, if they reflect a situation with locally reworked faunas, but are essentially in situ, they are parautochthonous assemblages.

In this respect, the history of shell burial and exhumation is strongly associated to the taphonomically active zone (TAZ), defined by Aller (1982) as the zone near the sediment–water interface where pore waters are undersaturated with respect to

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aragonite and calcite, and where most dissolution of carbonate minerals occurs. The length of time a shell remains at the surface and the time it spends buried just below the surface in the TAZ are significant factors in determining whether the shell will become part of a preserved fossil assemblage (Parsons-Hubbard et al. 1999). For futher details on taphonomy of marine shelly faunas see Kidwell and Bosence (1991).

2.2 Taphonomic Attributes

The nature of a fossil concentration is defined by taphonomic attributes (i.e., preservational features), and this kind of study allows death assemblages to be interpreted by observing the fossil remains. One way to do this is to analyze different taphonomic attributes according to different taphonomic grades (Fig. 2.1), for each sample and for a target species (i.e., the most common and/or best preserved species). The results are then averaged over the entire sample for comparisons with other sites/regions. Some of the taphonomic attributes most frequently used in mollusk shells are the following:

The *ratio of opposite valves* refers to the number of left and right valves of a particular species in each assemblage, and this feature is useful for evaluating transport from the original community. Another common feature is *fragmentation*, which is associated with the breakage of shells and serves as a proxy for environmental energy. The degree of shell fragmentation tends to be highest in environments with high water turbulence and coarse substrates, such as beaches and tidal channels, due to the impact of other shells, rocks and waves (Parsons and Brett 1991), although it can be influenced by ecological interactions, like shell-breaking predation or bioturbation (Zuschin et al. 2003). As an example, the degree of fragmentation can be estimated following a three-grade scale: whole shell (unbroken), broken shell (up to 50 % broken) and fragment (more than 50 % of the entire shell is absent).

It is also important to analyze the degree of surface alteration, which is generally related to the abrasion, corrosion or bioerosion of skeletons (Parsons and Brett 1991). *Abrasion* of shells occurs when they are exposed to moving particles or when the shells themselves are moved relative to other particles. It is produced by near-shore waves, currents or tidal action, and the most common effect of abrasion on mollusk shells is the loss of surface ornamentation. *Corrosion* on shell surfaces is frequently produced by chemical dissolution. Different skeletons display different solubility in acidic solutions. Calcitic hard parts with high magnesium carbonate content (e.g., echinoderms) are the most soluble, followed by aragonitic and low magnesium calcitic hard parts (Flessa and Brown 1983). Brett and Baird (1986) introduced the term *corrasion* to describe the degradation of shell surfaces when it is difficult to distinguish between abrasion and corrosion. *Wear*, related to abrasive agents, is also used to evaluate surface alteration. *Bioerosion* refers to the alteration of shells through the activity of organisms, usually in search of either food or shelter, and may take the form of boring, rasping, etching, breakage or abrasion of the shell. Another feature, *encrustation*, which refers to

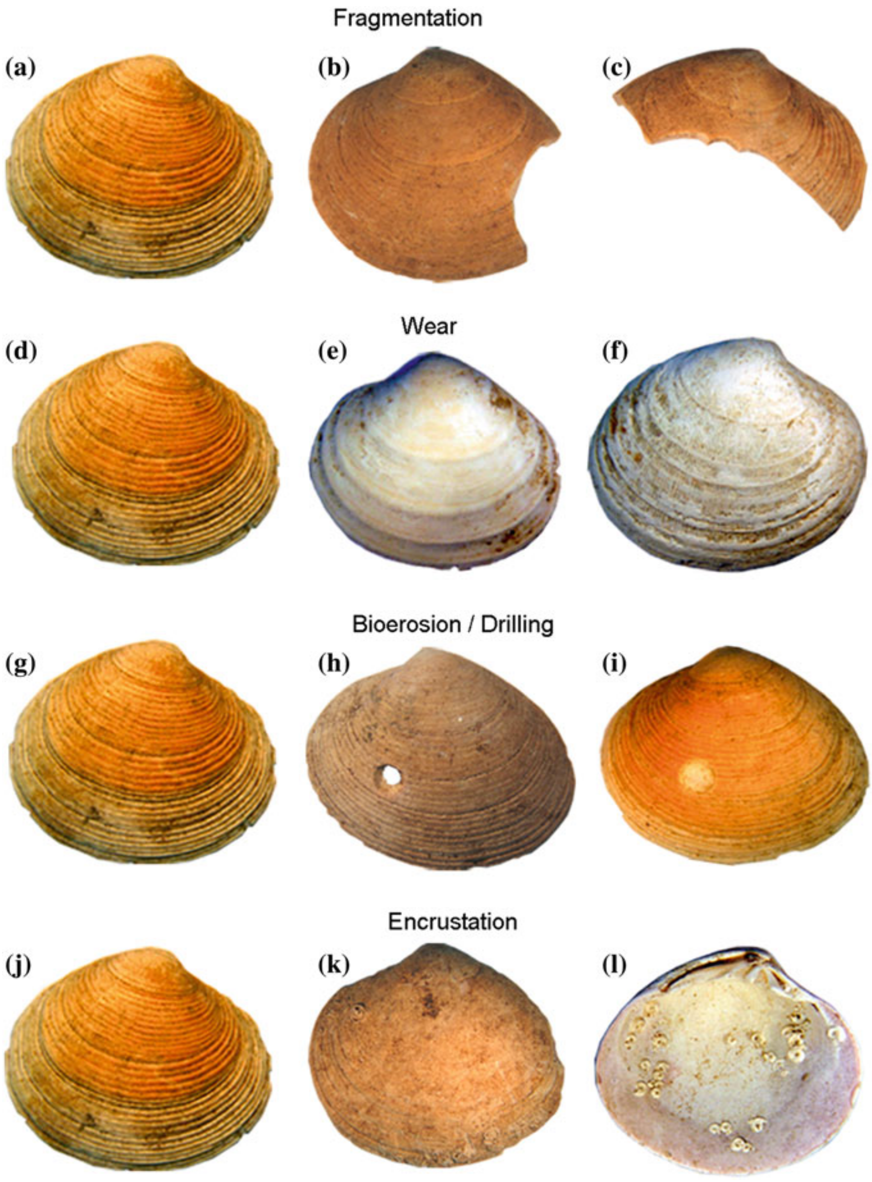

Fig. 2.1 *Tawera gayi* shells displaying three taphonomic grades for fragmentation, wear, and bioerosion and encrustation. **a** Unbroken shell, **b** Broken shell, **c** Fragmented shell, **d** Shell with ornamented surface, not abraded, **e** Shell with abraded surface, **f** Shell with internal layer exposed, **g** Unbored shell, **h** Bored shell, **i** Shell with incomplete drill-hole, **j** Shell without encrusters, **k** Shell with encrusters on external surface, **l** Shell with encrusters on the internal surface (after Gordillo et al. 2011)

organisms that use shells to live, is a good indicator of the duration of shell exposure at the sediment–water interface (Parsons and Brett 1991); hard-parts are often encrusted after death.

To analyze the percentage of fragmentation, surface alteration or bioerosion over an entire sample, different taphonomic categories are useful for further interpretations.

Finally, *size-sorting* involves the segregation of fossil elements, and reflects prolonged exposure to currents, selective winnowing and transport of shells by currents throughout different hydrodynamic events (Speyer and Brett 1988).

The analysis of ecological features such as mode of life is also useful for taphonomic studies. When considering life position with respect to sediment, mollusks are classified as *epifauna* when they live on a surface such as the sea floor, or on other organisms, and as *infauna* when they live in the substrate, especially when they are buried in a soft sea bottom. However, intergradation between the two categories makes this classification somewhat arbitrary and artificial, so a third intermediate category, *semi-infaunal* (Stanley 1970), can be applied to organisms that live partially buried in the substratum.

2.3 Exhuming Clams and Chitons

In southern South America, the shell remains of living and fossil specimens of five bivalves, including mytilids and venerids from the Beagle Channel and the Strait of Magellan, have provided valuable clues to local variations in physical factors such as current speed, wave action and freshwater input along these coasts during the Holocene (Cárdenas and Gordillo 2009; Gordillo et al. 2010, 2011).

According to taphonomic analyses, two types of environment exist on the coasts of Tierra del Fuego: a high energy environment in the Strait of Magellan terraces and a low to moderate energy environment in the Beagle Channel. In the Strait of Magellan, the mytilids (epifauna) show high fragmentation and abrasion, thus implying that they were subject to long exposure on the sea bottom before burial. It is also possible that these taxa experienced shell transport in abrasive sediment due to currents in a high-energy setting such as a foreshore environment, and/or multiple reworking episodes (Speyer and Brett 1991). In the Beagle Channel, fossil assemblages have moderate fragmentation and abrasion, thus indicating a low to moderate energy environment with a dominance of soft bottoms such as sand or small gravel. Venerids (infaunal or semi-infaunal species) are well-preserved in both zones of Tierra del Fuego, and although abrasion and fragmentation in the deposits are moderate, this can be attributed to high bioerosion of their valves caused mainly by boring gastropods and/or encrusting elements on the surface of the shell (Zuschin and Stanton 2001). In this respect, results show a relationship between the levels of bioerosion and fragmentation in the deposits from the Strait of Magellan, i.e., deposits with high bioerosion also show high fragmentation. Nonetheless, in other sites along the Beagle Channel

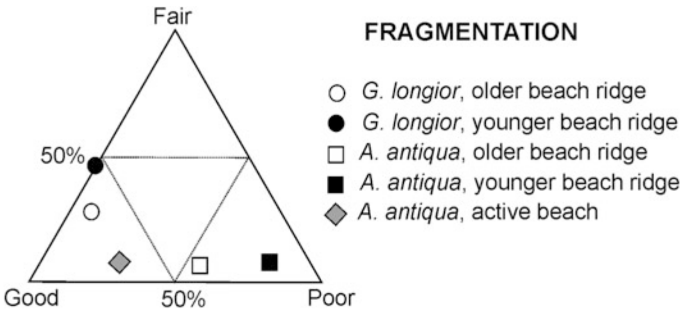

Fig. 2.2 Distribution of different taphonomic grades for the attribute fragmentation, considered in *Glycymeris longior* and *Ameghinomya antiqua* from Holocene beach ridges and modern *A. antiqua* shells from the present day (active) beach. The graph shows a higher percentage of broken shells in the youngest beach ridge, thus implying different environmental conditions with respect to the older one. *A. antiqua* samples from these deposits are closer to the Poor apex of the *triangle*, thus indicating shells with fractures greater than 50 %

(the Alakush and Ushuaia sites), this relationship does not exist and the high fragmentation of venerids could be associated with different postmortem processes. In particular, venerids showed a higher preservation potential than mytilids, and their infaunal life cycle and fast burial rate make them more reliable specimens to use in further taphonomic analyses.

In Patagonia, Argentina, the coastal area of Puerto Lobos (Chubut, northern Patagonia, 42°00′S 65°4′W) was chosen for the taphonomic analysis (Fig. 2.2) of two common bivalve species from the area (*Glycymeris longior* and *Ameghinomya antiqua*). This was useful for evaluating changes in environmental conditions, such as waves and currents (Boretto et al. 2013). *Glycymeris longior* is typical of the Argentinean Province, located to the north, while *Ameghinomya antiqua* is typical of the Magellan Province, located to the south. However, the two species coexist in Puerto Lobos, which is located between these two malacological provinces. For taphonomic analysis, mollusk shells (N = 268) were collected from the active beach and from two Holocene beach ridges: the older ridge was dated at 3310 ± 90 years BP, while the younger ridge was dated at 750 ± 75 years BP (Bayarsky and Codignotto 1982).

Data was analyzed using the ternary taphograms proposed by Kowalewski et al. (1995), which have a semiquantitative character. The corners of the equilateral triangles are classified as Good (little or no development of a particular attribute), Fair (moderate development of a taphonomic characteristic), or Poor (high development of the attribute). The entire sample can be characterized by the proportion of shells in each of the three categories (Kowalewski et al. 1995). For Fragmentation, the grade Good indicates no fractures; Fair represents less than 50 % broken shells; and Poor is when more than 50 % of the shells are broken. *G. longior* assemblages from the older Holocene deposit are located close to the Good grade, with a tendency towards Fair, thus indicating the preservation of whole shells, or shells that are less than 50 % broken. It also shows a higher percentage of fragmented *G. longior* shells

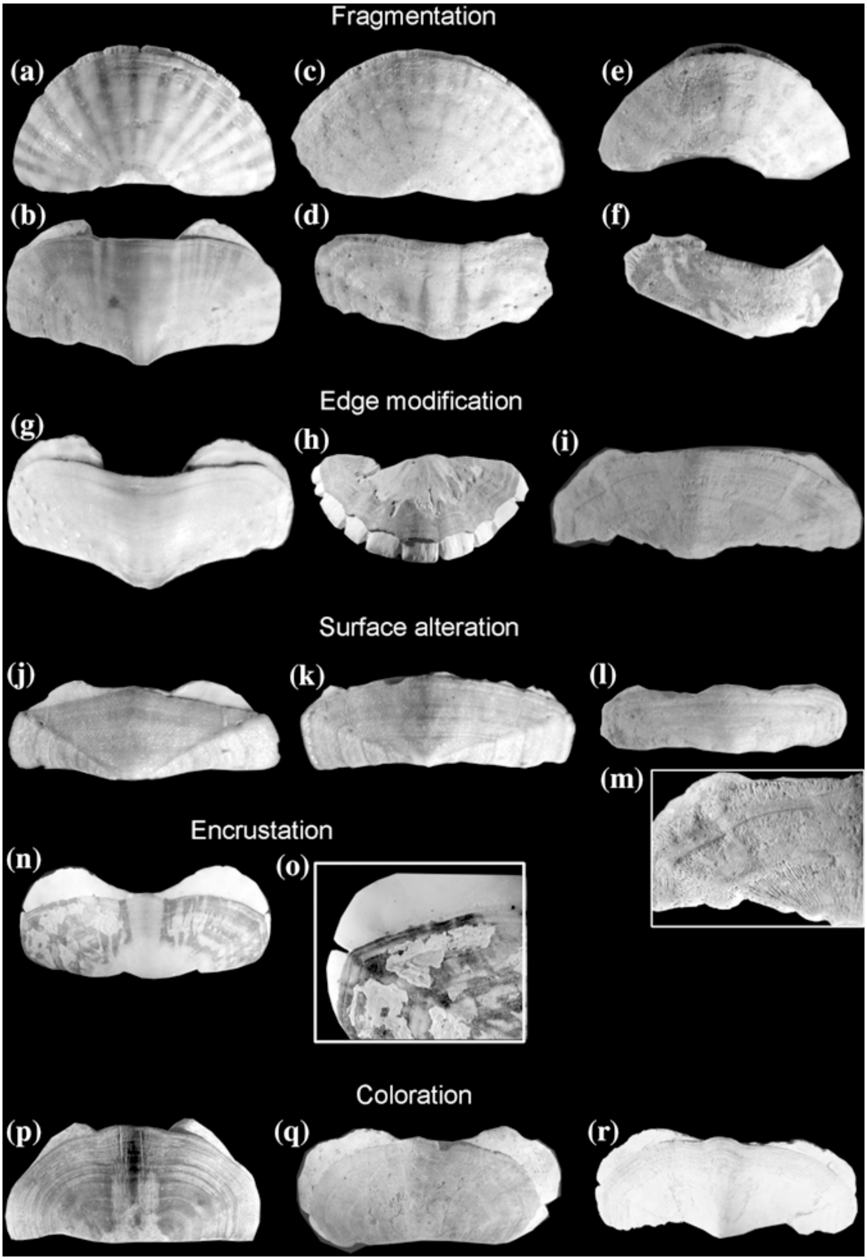

Fig. 2.3 Taphonomic attributes and grades using chiton plates. Fragmentation: **a**, **b** Whole plates, **c, d** Broken plates, **e**, **f** Fragments. Edge modification: **g** Edge without modification, **h** Chipped edge, **i** Polished edge. Surface alteration: **j** Surface without changes, **k** Surface alteration up to 50 %, **l**, **m** Completely altered surface. Encrustation: **n**, **o** Intermediate plate with encrusting algae. *Coloration* **p** Plate with original color, **q** Discolored plate, **r** Colorless plate (*white* washed) (after Gordillo 2007)

in the younger deposit, thus implying different environmental conditions. *A. antiqua* samples from these deposits are closer to the Poor apex of the triangle, thus indicating shells with fractures greater than 50 %. As in the previous case, samples from the younger deposit display a higher degree of fracturing than samples collected from the older deposit. *A. antiqua* shells sampled from the modern beach are preserved whole (Good-Poor grade). These trends indicate greater energy in the depositional environment for the youngest beach ridge, since both species are more vulnerable to fracture in relation to those analyzed in the oldest beach ridge. Nevertheless, these results are best interpreted in conjunction with intrinsic properties of resistance to shell breakage (see Chap. 3).

A third example comes from the analysis of taphonomic and paleontological attributes in Holocene chitons (Fig. 2.3). Gordillo (2007) showed that the taphonomic condition of a chiton plate is the result of biological, ecological and environmental factors, and in this study the surface of a high percentage of chiton plates was affected. It was also considered highly probable that the dissolution process is post-depositional and is associated with changes in pH, since several of these deposits are currently associated with brackish or freshwater environments. This situation, coupled with the frequent rainfall and snow in the region, would have led to an acidic environment that favored the dissolution of the carbonates within the plates. However, unlike chitons, dissolution did not significantly alter the bivalves present in the same associations. The reason for this inequality may be linked to differences in the microstructure and the organic content of the bivalve shells and chiton plates. Apparently, the chiton plates have pores associated with an interconnecting network of microtubules (for housing soft tissue with a sensory function), and this raises the proportion of organic content and the flow capacity of interstitial water, thus favoring dissolution. The environmental acidity as a cause of dissolution, and the relationship between microstructure and differential preservation of mollusk shells, has also been considered by other authors (e.g., Glover and Kidwell 1993; Isaji 1993). The exposure of internal layers obtained from raised beach plates could also be associated with some epibionts not preserved in the fossil record (e.g., algae, sponges), which could have acted as agents of bioerosion and facilitators of dissolution. This example with chiton plates shows that they are also suitable for evaluating the post-mortem events that took place up to when they were found within the fossil record.

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