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Taphonomic degradation of molluscan remains during thirteen years on the continental shelf and slope of the northwestern Gulf of Mexico

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ABSTRACT

In 1993, SSETI (Shelf and Slope Experimental Taphonomy Initiative) deployed shells of a suite of molluscan species in a variety of environments of preservation (EOPs) covering a range of depths and sediment types on the Gulf of Mexico continental shelf and upper slope, with the goal of measuring taphonomic rates over an extended period of time. SSETI retrieved shells from these EOPs after 2, 8, and 13 years. The degree of shell degradation was significantly influenced by species, elapsed time-since-deployment, and EOP. A suite of 'physical' taphonomic processes, such as dissolution, abrasion, discoloration, and edge alteration, increased in severity over the 13 years; fragmentation occurred in some species. Dissolution proceeded apace; however the incidence of chalkiness declined from high levels observed after a few years while the more extreme levels of dissolution, such as the development of a soft or deeply-dissolved surface, rose significantly in frequency. The incidence of original color declined, while fading of original color increased. Brown-to-red and green discoloration rose rapidly in the first eight years and then declined, leaving a faded shell surface. Between-habitat differences in degradation rate were significant for most taphonomic attributes. Between-species differences were minor in comparison. Thus, taphofacies, the product of the independent actions of a suite of taphonomic processes, originate from and provide information on environmental conditions. Species composition has a lesser inherent influence on the outcome. Not uncommonly, the rates of change in shell condition differed significantly between EOPs although the direction of change was coincident. This was particularly true of the summary indices such as maximum discoloration or the average degree of dissolution. The taphonomic process is nonlinear in time. Nonlinearity is EOP-dependent, becoming a defining attribute leading to disparate taphofacies types. Some taphonomic processes cannot proceed expeditiously without prior alteration of the shell through other taphonomic means. Some taphonomic conditions such as chalkiness can be intermediate states. The presumption that similar taphonomic characteristics between EOPs indicate similar environmental processes operating at similar rates is falsified by SSETI sites in which similar taphonomic indices at Year 13 accrued from different time-varying degradational rates during the preceding years.

1. Introduction

The central hypothesis of most taphonomic studies is that taphonomic characteristics co-occur predictably, defining "taphofacies", and that these can be used to characterize major environments of deposition (Brett and Baird, 1986). Furthermore, the geographic distribution of these taphofacies should map environmental gradients, such as depth and sediment type, permitting assemblage taphonomic signature to be interpreted within the framework of preservational potential and environment (Brett and Baird, 1986; Callender and Powell, 2000; Callender et al., 1992; Kidwell et al., 1986; Meldahl and Flessa, 1990). Recognition of taphofacies accordingly can provide insight into the preservational biases that modified the fossil assemblage from the original assemblage of organisms (e.g., Behrensmeyer, 1984; Kidwell and Flessa, 1995; Parsons and Brett, 1991), limited only to the

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degree to which the preservational process creating the taphofacies is understood. Conceptual and numerical taphonomic models have been developed to describe the process of preservation (Kidwell, 1986a; Kowalewski and Miśniakiewicz, 1993; Olszewski, 1999, 2004; Powell, 1992; Shimoyama and Fujisaka, 1992), but these still provide limited resolution of the time course of taphonomic processes that affect the preservation of molluscan skeletal remains, including decomposition, fragmentation, dissolution, abrasion, and precipitation (Canfield and Raiswell, 1991; Dominici, 2004; Flessa et al., 1993; Parsons and Brett, 1991; Powell et al., 1989; Tomašových, 2004a) and how they conspire to ultimately generate the taphofacies.

Taphonomic processes can exert a significant influence within months of death, if not simultaneously with it (e.g., Christmas et al., 1997; Kiene et al., 1995; Simon et al., 1994; Walker, 2001; Zuschin et al., 2003), but also progressively degrade remains over a longer period of time (Callender et al., 1994; Lescinsky et al., 2002; Smith and Nelson, 2003; Wisshak et al., 2005). What is known about these processes suggests that taphonomic rates may themselves be time-dependent, so that knowledge of the preservational state of skeletal remains at any particular time after death may not be predictive of a future state. Moreover, the preservational process is modulated by such processes as burial, exhumation, transportation, and encrustation (Carroll et al., 2003; Kidwell, 1986b; Powell, 1992; Walker, 2001; Walker and Goldstein, 1999; Zuschin et al., 1999), which may markedly modify the rate of degradation over time (Best and Kidwell, 2000; Davies et al., 1989; Dominici, 2004; Martin et al., 1996). Thus, taphofacies are the product of many processes of considerable temporal extent and variability. To date, however, only limited empirical information exists concerning the processes determining the fate of skeletal material after the first few months to years of taphonomic time and in only one case do observations cover even a period of four years (e.g., Behrensmeyer et al., 2000; Callender et al., 1994, 2002, Powell et al., 2002, 2008, in press). Only a single quantitative evaluation of a carbonate budget exists for a dominant molluscan species based on observed rates of production and loss over a period of years (Powell and Klinck, 2007; Powell et al., 2006). In this case, for eastern oysters *Crassostrea virginica*, the carbonate loss rate was surprisingly high; however application of this example is limited as the mechanisms of shell destruction, though known in general, still remain poorly understood. Thus, the attainment of the full promise of the taphofacies approach is precluded by a temporally-limited understanding of the taphonomic process in an edaphically-limited set of environments of preservation.

The SSETI (Shelf and Slope Experimental Taphonomy Initiative) program was established with the principal goal of measuring taphonomic rates of skeletal material over an extended period of time in a wide range of EOPs to address the temporal and edaphic limitations in the database underpinning our apprehension of the taphonomic process (Parsons et al., 1997; Parsons-Hubbard et al., 1999, 2001). In 1993, SSETI deployed experiments in the Gulf of Mexico (Fig. 1) in a series of distinctive EOPs (environments of preservation). Experiments were retrieved two and eight years later, analyses of which have been reported by Powell et al. (2002, 2008). In 2006, SSETI retrieved experiments from 11 EOPs after thirteen years of deployment time. The sites in the Gulf of Mexico include terrigenous sands and muds, brine influenced regions, and deepwater open-shelf carbonate environments. Here, we describe the degree and rate of taphonomic degradation occurring over 13 years for molluscan skeletal remains deployed at these EOPs. We focus on the classic 'physical' taphonomic processes, recognizing that many are biologically mediated, such as dissolution, abrasion, discoloration, and edge alteration, leaving to subsequent analyses the biological community of epibionts and endobionts that generate their own imprint on the preservational process (Powell et al., 2008, in press; Sanders and Krainer, 2005; Stefaniak et al., 2005, Young and Nelson, 1985).

2. Methods

2.1. Site description

Parsons et al. (1997), Parsons-Hubbard et al. (1999), and Powell et al. (2008) provide descriptions of the Gulf of Mexico sites. Experiments were deployed in 1993 by the submersible *Johnson-Sea-Link* on a transect off Galveston, Texas and at selected EOPs along the shelf edge and slope to the northeast. A series of EOPs were sited at the East Flower Garden (EFG), a deep reef atop a salt diapir (Bright and Powell, 1983; Gardner et al., 1998; Lugo-Fernández, 1998). Experiments were deployed on the deep reefal coralline-algal dominated hardground, in an anoxic brine pool (200‰) (Powell et al., 1986; Rezak and Bright, 1981), in a brine-filled canyon downslope from the pool (Gittings et al., 1984), at the canyon mouth where dilution returns salinity to near normal (Powell et al., 1986), and on the carbonate sand of the canyon fan downslope of the canyon mouth (Powell et al., 1983). Experiments were also deployed at Parker Bank, another diapir-supported shelf-edge bank (Rezak et al., 1990). The center of this bank has collapsed leaving a central basin filled with large carbonate blocks and fine ooze. Experiments were deployed on the carbonate rim that supports a thriving deep-water hard-bottom community and in the central basin.

The sites located off Galveston were designed to document taphonomic rates typical of continental shelf and slope terrigenous sediments in the northwestern Gulf of Mexico. The outer continental shelf site is a relatively shell-rich terrigenous mud representative of a wide expanse of the upper Texas outer continental shelf (Curray, 1960; Gallaway, 1988; Parker, 1960). Sulfate reduction begins within millimeters of the sediment surface (Lin and Morse, 1991). The upper continental slope site is also representative of the normal continental slope found throughout most of the western Gulf of Mexico. Sediments contain pelagic carbonates and a very sparse benthic fauna. Sulfate reduction does not start until well below the sediment–water interface (Lin and Morse, 1991).

Experiments were deployed at two very different petroleum seeps with lush chemoautotrophic-based communities on the continental slope. Garden Banks GB425 is a massive clam (lucinid and thyasirid) community. Green Canyon GC234 is mussel and tubeworm dominated (Callender and Powell, 1999, 2000). GC234 and GB425 are in a geologically and bathymetrically complex region characterized by active salt diapirism, associated faulting (Behrens, 1988; Bouma et al., 1980, 1981), widespread active seepage of liquid and gaseous hydrocarbons (Kennicutt et al., 1988a,b), and locally high sedimentation rates (MacDonald et al., 2000; Roberts and Carney, 1997). More details can be found in Bergquist et al. (2003), Callender and Powell (1997), Carney (1994), and MacAvoy et al. (2002).

2.2. Experimental design

The SSETI experimental design is described in detail in Parsons et al. (1997) and summarized briefly here. Each experimental array consisted of a series of 1-cm-mesh bags attached to a 1.5-m PVC pole. To each pole was added a 12-kg weight to counter a 25-cm-square float made of 6-mm-thick sheet polypropylene, that served to mark the location of the experiment even when buried. The PVC pole was unattached to the bottom, anchored only by the 12-kg weight, and so was free to move, given sufficient current and wave action. Two of the mesh bags on each pole contained molluscan shells, typically five individuals of five different species, each species compartmentalized from the others by plastic cable ties. Molluscan species deployed included the ocean quahog *Arctica islandica*, the mussel *Mytilus edulis*, the lucinid *Codakia orbicularis*, the scallop *Argopecten irradians*, the conch *Strombus luhuanus*, and the turritellid, *Turritella terebra*.

The history of recovery of SSETI experiments after 2 and 8 years in the Gulf of Mexico is provided by Callender et al. (2002), Powell et al.