

Differential Preservation of Gravel-sized Bioclasts in Alpheid- versus Callianassid-Bioturbated Muddy Reefal Sediments

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Infaunal bivalve shells were extracted from sediment cores taken in shallow seas off Phuket, South Thailand, and were scored for four types of taphonomic degradation to assess the effect that different types of bioturbation have on the preservation of such bioclasts. This gravel-sized fraction of off-reef biogenic (bivalve) sediments showed variation in the extent of degradation, depending on whether it was found in an area bioturbated by callianassid or alpheid shrimps. Cores taken in the alpheid area have a higher proportion of grains with poorly defined shape and ornamentation, a loss of surface luster and high levels of microbioerosion. In contrast, those from the callianassid area have a higher proportion of shiny, sharply defined fragments and a lower level of microbioerosion than those from the alpheid area. It is concluded that the different nature of bioturbation in the two areas accounts for the difference in preservation. In working the sediment, callianassids bury the gravel fraction, while alpheids repeatedly bring it to the sediment surface, thus exposing it to higher levels of physical and microbiological erosion. The shrimps' activities result in a difference in preservation potential of fine and coarse sediments, and this taphonomic bias will affect taphofacies interpretation. Rapid burial of gravel by callianassids also has implications for time-averaging, as a shell fragment's condition is more indicative of its residence time at the surface-water interface than its age.

INTRODUCTION

Taphonomic alteration of shells includes dissolution, fragmentation, surface abrasion, size sorting, bioerosion, and encrustation (Aller, 1982; Flessa and Brown, 1983; Davies et al., 1989a, 1990; Scoffin, 1992; Flessa et al., 1993; Cutler, 1995). Flessa and Brown (1983) and Callender et al. (1994) provided some evidence for the order in which these occur, from initial development of a chalky surface through to heavy etching and pitting with resultant loss of shell sculpture and thinning of the shell.

Carbonate grains in marine sediments may be degraded through dissolution, microbioerosion, physical abrasion, and fragmentation. Breakdown is most rapid at the sediment-water interface and in the surficial sediments, wherein carbonate dissolution is fastest (Aller, 1982; Aller and Yingst, 1985; Green et al., 1993; Murray and Alve,

1999; Walker and Goldstein, 1999) and microborers most abundant. Microborers, such as algae and fungi, can be an important direct source of carbonate dissolution (e.g., Tudhope and Risk, 1985; Scoffin, 1992) and also increase rates of inorganic dissolution by increasing grain-surface area (Flessa and Brown, 1983; Tudhope and Risk, 1985). Bioerosion also may cause structural weakening of grains. Like carbonate dissolution, rates of bioerosion decrease rapidly with depth in the sediment (Davies et al., 1989b and references therein), partly because many of the dominant groups of microbioeroders (e.g., filamentous green algae and cyanobacteria) are photosynthetic. Therefore, grains must be buried quickly in order to slow taphonomic loss and enhance preservation (e.g., Cummins et al., 1986; Davies et al., 1989b; Walker and Goldstein, 1999).

Bioturbation may speed up or slow down the degradation of carbonate grains in a number of ways. The turnover of sediment may cause a decrease in grain size through breakage and/or affect sediment chemistry (Fig. 1). Burrows and sediment mixing can extend the taphonomically active zone (TAZ; Davies et al., 1989b) horizontally and vertically downwards (Aller, 1983; Cummins et al., 1986; Davies et al., 1989a; Aller and Aller, 1998; Walker and Goldstein, 1999), and also bring to the surface previously buried grains (Martin et al., 1996), thus exposing them to harsher surface conditions. Alternatively, bioturbation potentially can enhance preservation, if carbonate grains are buried or fall into large deep burrows, bypassing the taphonomically active zone (Aller, 1982; Flessa et al., 1993; Martin et al., 1996). Tudhope and Scoffin (1984) extended this idea further, noting that callianassids actively removed coarse carbonate grains from the influence of microbioerosion at the sediment surface.

Other studies that include detailed examination of the degradation of carbonate grains have concentrated either on the effects of physical processes (e.g., transport) on their taphonomic attributes (Davies et al., 1989a; Cutler, 1995), the relation between taphonomic condition and shell age (Flessa et al., 1993; Callender et al., 1994), or the differences in extent of degradation between different grain types (Callender et al., 1994; Martin et al., 1996; Walker and Goldstein, 1999). Some have taken an experimental approach (e.g., Flessa and Brown, 1983; Green et al., 1992; Glover and Kidwell, 1993). Most studies make the general comment that bioturbation increases degradation (e.g., Aller, 1982; Davies et al., 1989b; Green et al., 1992; Walker and Goldstein, 1999). Aller (1982) is one of the few authors to consider the wider picture; he produced one of the most detailed studies to consider bioturbation, describing its effects on sediment chemistry and, thus, carbonate degradation.

Objectives

In this study, the effects of callianassid and alpheid shrimps on the sediment are examined. Both types of shrimp continually turn over the upper part of the sediment in which they live (Bradshaw 1997a,b), each crustacean having a different sorting effect. Callianassids bring only fine particles to the sediment surface, burying and concentrating coarser grains at depth. In contrast, alpheids excavate and bring to the surface grains of all sizes, up to particles of several centimeters diameter. The hy-

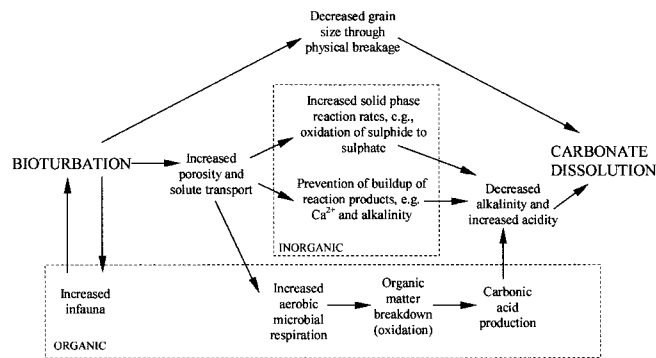


FIGURE 1—Summary of the ways in which bioturbation can increase carbonate dissolution. (Based on information from Aller, 1982; Flessa and Brown, 1983; Davies et al., 1989b; Scoffin, 1992; Green et al., 1992, 1993; Aller and Yingst, 1995; Aller and Aller, 1998; Walker and Goldstein, 1999).

pothesis tested in this study was that gravel-sized carbonate grains in an area burrowed by alpheid would show more taphonomic alteration than those from an area burrowed by callianassids.

STUDY AREA

Phuket Island lies off the SW coast of the Thai Peninsula at 8°00'N and 98°20'E. To the west is the Andaman Sea (East Indian Ocean), and to the east the relatively sheltered and turbid waters of Phangnga Bay (Fig. 2).

At the south tip of Cape Panwa is Pump House Bay, a small bay (150 m wide) that contains a coral shingle beach and a small reef (Fig. 2). Immediately seawards of the reef edge (at about 4 m water depth) is a 2-to-5-m-wide band of dead branching coral debris beyond which are compact, smooth, gravelly muds. Despite strong currents, this mud is not in constant motion from wave or current action and is probably only significantly disturbed physically during infrequent storms (Bradshaw, 1997b). In this muddy zone, there is no epifauna or epiflora, but abundant burrowers create a dense mosaic of holes and mounds on the seabed. Three main burrow types are found in discrete areas moving offshore. In water depths of 4–6 m, small alpheid shrimp burrows occur closest to the reef. Larger alpheid burrows, which spiral down to depths of >60 cm in the sediment, occur at water depths of 6–8 m (c.75 m offshore). Complex deep burrows made by callianassid shrimps occur c.100 m offshore (9–12 m water depth; Bradshaw, 1997b). Each of these three areas is dominated by the particular crustacean burrow type, and they are the only burrows to reach such depths in the sediment.

Sediments

The shallow marine sediments around Cape Panwa are a mixture of land-derived sediments (quartz, kaolinite, and illite: Carr et al., 1991) and reef-related carbonates. Off Pump House Bay, in the offshore direction, mean grain size of surface sediments decreases and the surface fine layer increases in thickness. Sorting is very poor throughout all cores in all areas at all sediment depths. There is a gradual increase in mean grain size down core in all areas, with a coarse peak at 30–50 cm or 40–60 cm sediment

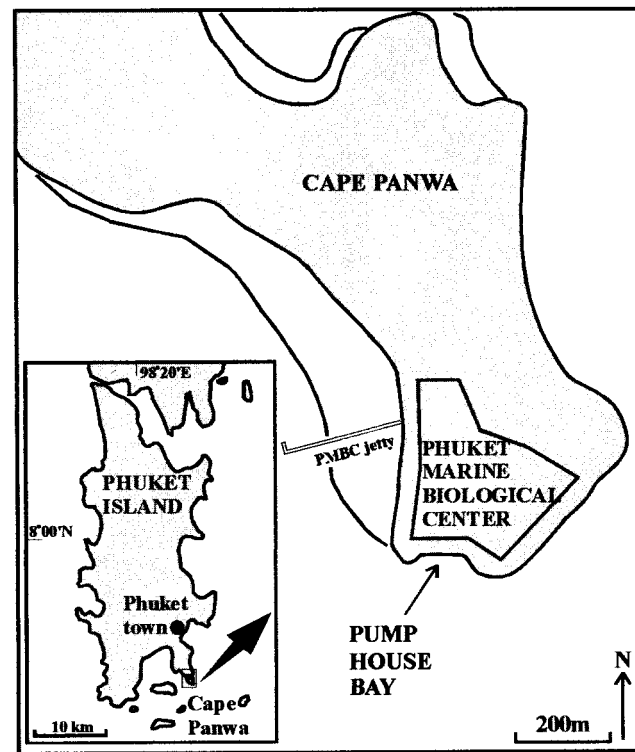


FIGURE 2—Location of the study site, Pump House Bay (main map) in Phuket (inset).

depth in areas dominated by off-reef alpheid and callianassid shrimps, respectively. This coarse peak is thought to be a storm deposit from 1988 (Bradshaw, 1997a, b).

METHODS

Grain Analysis

Plastic tube corers (133-cm lengths of plastic piping with internal diameter of 4.2 cm) were used to sample the subsurface sediment to a maximum depth of 110 cm. Five cores from the alpheid-burrowed area (A1–5) and four cores from the callianassid-burrowed area (C1–4) were obtained by pushing the corers into the sediment by hand or with a mallet. Each core was extruded into a core holder and 5-cm-thick slices of sediment were cut using a sharp blade. These sections were washed through a 5-mm mesh to retain the >5-mm gravel fraction.

All the bivalves from each washed sample were extracted for further analysis, except those that were obviously reef-derived (e.g., encrusting oysters and coral-boring species). The latter were removed because they could have spent variable amounts of time on the reef subjected to surface processes before entering the sediment. In contrast, any signs of damage on skeletal grains derived from infaunal bivalves were likely to have occurred due to processes in or on the sediment since the organism's death. Bivalves were chosen because they were common throughout all cores. No epifaunal bivalves were seen on the sediments at this site.

Every infaunal bivalve-shell fragment from each of the nine cores was scored on a relative scale for four types of

TABLE 1—Criteria used to score the four types of taphonomic degradation. "Edge of grain" refers to both the natural shell edge and any edges caused by fragmentation. Rounding and loss of surface luster may be due to abrasion and/or dissolution.

Taphonomic attribute	Criteria levels			
Rounding	Very sharp Edge of grain and any surface ornamentation well defined, as in a live bivalve	Quite sharp Edge of grain slightly worn or broken. Any surface ornamentation still obvious, but not as well-defined as in a fresh bivalve	Quite rounded Features on the edge of grain and ornamentation still visible but unclear	Very rounded Edge of grain completely rounded and no surface ornamentation visible
Shininess	Very shiny Periostracum intact and/or interior of valve shiny and fresh. Original color of shell still clear, muscle scars and pallial line clearly visible	Quite shiny Some periostracum present and/or some evidence of shell coloration, muscle scars or pallial line. Shell still has some luster	Quite dull Surface luster lost, and slight chalkiness on the surface	Very dull Surface of fragment heavily pitted with a chalky texture
Bioerosion	None None visible	Little A few small superficial holes visible	Extensive Heavy bioerosion: >30% of the surface bioeroded, or a few deep holes	
Encrustation	None None visible	Little A few small encrusting colonies or individuals visible.	Extensive Heavy encrustation, covering >30% of the grain surface	

grain degradation (modified from Davies et al., 1989a): degree of rounding of the fragment edge and ornamentation, degree of shininess of shell surface, extent of microbioerosion, and extent of encrustation (Table 1).

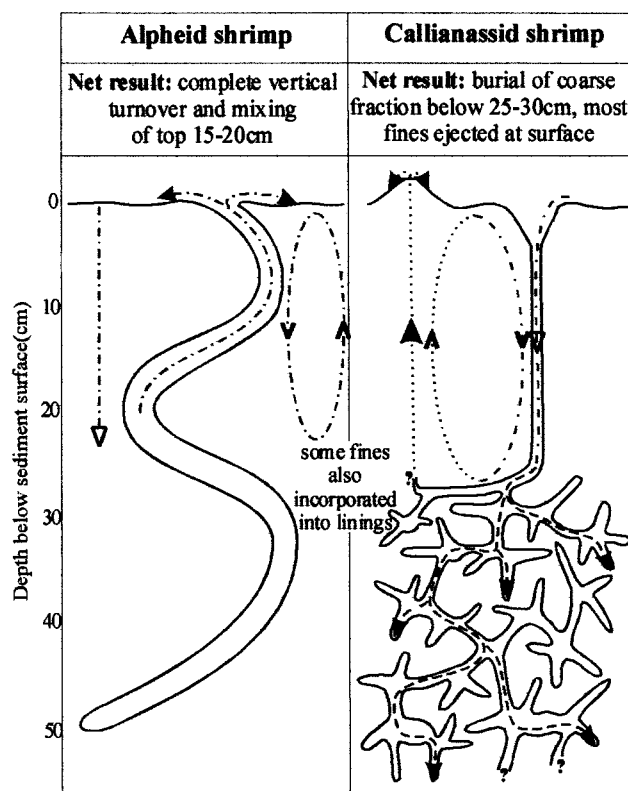


FIGURE 3—Schematic diagram of alpheid and callianassid burrows to show the turnover of different grain sizes. Symbols: ► active movement, ◄ passive movement, > net movement, fine grains, ----- coarse grains, -·-·-· all sediment.

Turnover Rates

Sediment turnover rates were estimated by measuring the diameter and depth of callianassid craters and calculating their volume using the formula for a cone (volume = $\frac{1}{2}\pi r^2 d$, where r = radius of the crater at the surface, d = depth of the crater). The approximate rate at which new craters were excavated was measured by twice-daily monitoring by divers.

Twice-daily diver surveys also showed that alpheids dug a new shaft to the surface approximately once every day. Airlift excavation enabled the length and width of this new shaft to be measured (Fig. 3), and the volume was calculated using the formula for a cylinder (volume = $\pi r^2 l$, where r = radius of burrow, l = length).

The estimates of sediment turnover per burrow obtained by these methods were converted to turnover per m^2 of seabed by measuring the density of burrows along belt transects. Sediment volumes also were converted to weights and, using measured values for the proportion of the sediment consisting of grains >4-mm diameter, turnover rates of the coarse fraction by alpheids and callianassids were calculated.

Tracer-sediment experiments also were conducted to investigate rates of sediment turnover and differential treatment of grains by the shrimps. The tracer sediment was prepared by mixing different size fractions of beach sand and carbonate gravel with fluorescent paint, spreading it into a thin layer and oven drying it at 60°C. The dried layer was then crushed to separate the grains and sieved to produce various size fractions of colored sediment. Aliquots of 20 g of tracer sediment (each comprising 2 g 63–125 μm , 2 g 125–250 μm , 2 g 250–710 μm , 2 g 720–

TABLE 2—Percentage abundances of each category of grain degradation. 'A' indicates cores from the alpheid area, 'C' those from the callianassid area.

Core no.	Grain edge/ornamentation				Shell surface				Microbioerosion			Encrustation			Frag-ments	n	
	Very sharp	Quite sharp	Quite round	Very round	Very shiny	Quite shiny	Quite dull	Very dull	None	Slight	Extensive	None	Slight	Extensive			Whole
A 38	1.86	26.71	31.68	39.75	2.48	20.50	24.22	52.80	28.57	16.77	54.66	78.88	15.53	5.59	9.94	90.06	161
A 39	14.73	36.43	29.46	19.38	10.85	15.50	19.38	54.26	34.11	31.78	34.11	87.60	12.40	0.00	14.73	85.27	129
A 44	24.50	23.84	17.88	33.77	17.88	21.85	17.22	43.05	41.72	13.91	44.37	85.43	13.91	0.66	13.91	86.09	151
A 45	4.14	30.34	40.69	24.83	2.76	21.38	33.79	42.07	37.93	23.45	38.62	79.31	16.55	4.14	12.41	87.59	145
A 46	12.34	40.91	28.57	18.18	9.74	27.92	32.47	29.87	44.81	29.22	25.97	87.66	12.34	0.00	12.99	87.01	154
mean	11.51	31.65	29.66	27.18	8.74	21.43	25.42	44.41	37.43	23.03	39.55	83.78	14.15	2.08	12.79	87.21	
A 40	16.51	45.87	25.69	11.93	11.93	26.61	28.44	33.03	50.46	29.36	20.18	94.50	5.50	0.00	14.68	85.32	109
A 41	1.28	31.41	30.77	36.54	3.85	23.72	23.72	48.72	33.97	23.08	42.95	81.41	16.67	1.92	8.33	91.67	156
C 42	21.30	36.11	26.85	15.74	22.22	25.93	21.30	30.56	50.00	25.00	25.00	81.48	17.59	0.93	16.67	83.33	108
C 43	16.30	47.83	21.74	14.13	18.48	25.00	30.43	26.09	61.96	20.65	17.39	80.43	18.48	1.09	8.70	91.30	92
mean	13.85	40.30	26.26	19.58	14.12	25.31	25.97	34.60	49.10	24.52	26.38	84.46	14.56	0.98	12.09	87.91	

2.36 mm, 2 g > 2.36 mm, and 10 g > 5 mm) were placed on the sediment surface at six callianassid and six alpheid burrow entrances. The location of the tracer was determined between 1 and 14 days later by taking sediment cores and by subsurface sampling burrows that had been excavated using an airlift suction device.

RESULTS

A summary of the frequencies of different grain types is shown in Table 2. Distinct differences exist between the characteristics of grains from the callianassid and alpheid areas (Fig. 4), with grains being less degraded in the callianassid area than the alpheid area. These results are sta-

tistically significant (Table 3), despite a high degree of variability between cores from each area. Grains from the alpheid area have significantly more rounded edges and ornamentation and are duller than expected, whereas grains from the callianassid area show the opposite pattern. There is also a higher-than-expected level of bioerosion in grains from the alpheid area, and lower than expected from the callianassid area. Levels of encrustation were low throughout the two areas and were not significantly different.

Chi-squared tests also were significant between cores within each area, but this was not due to any trend, but to the large variability between cores (see Discussion). It also is possible that the requirements of the chi-squared test were violated due to some categories containing less than 5% of the observations.

Turnover rates are presented in Table 4, based on an average callianassid crater volume of 353 cm³ (6 cm diameter, 25 cm deep) being excavated every two days, and an alpheid burrow extension of 60 cm³ (25 cm long, 1.75 cm diameter) being excavated every day. A conversion of 1 cm³ = 1.54 g was used. Callianassid and alpheid burrow densities were 24 per 100 m² and 13 per 100 m², respectively.

Tracer sediment of all grain sizes, but especially the >2-mm fraction, appeared in the callianassid burrows, 20 cm below the surface, in less than 24 hours. The finer fractions of tracer also were ejected by the callianassids in large quantities into the mounds in this time span. In the case of the alpheids, tracer sediment of all grain sizes was seen to be shoveled out of the burrow entrances onto the sediment surface within 12 hours. Small amounts of tracer also were found within the alpheid burrows, but this was more likely to have fallen in, as alpheids only were observed to actively transport sediment upwards from the burrow to the surface.

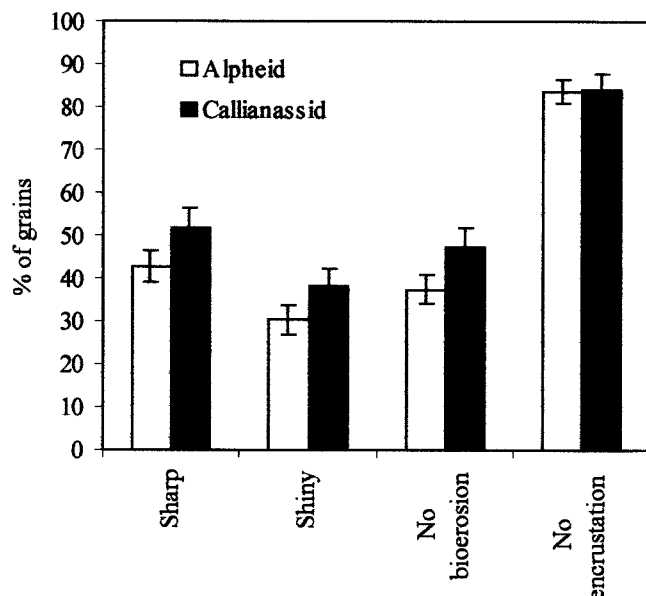


FIGURE 4—Differences in infaunal bivalve fragment degradation in areas bioturbated by alpheid or callianassid shrimps. 'Sharp' refers to the degree of roundness of the grain edges and shell ornamentation. 'Sharp' refers to the degree of roundness of the grain edges and shell ornamentation. 'Shiny' refers to the general freshness of the shell surface. Counts for different degrees of each characteristic (e.g., "very sharp" and "quite sharp") have been combined in this graph. Error bars show 95% confidence limits ($1.96 \times \text{S.E.}$).

DISCUSSION

Differential Preservation

There is a definite taphonomic bias to preservation: grains from the alpheid area have more rounded edges and more eroded ornamentation, and are duller and more microbioeroded when compared to those from the calli-

TABLE 3—Summary comparison of grain degradation from alpheid- and callianassid-burrowed areas. Chi-square test calculated using total number of grains in each category, summed for all cores from each area. ** = significant at $P < 0.01$, * = significant at $P < 0.05$.

Categories tested (alpheid vs callianassid area)	Chi-square value	Degrees of freedom	Significance
very sharp/sharp/smooth/very smooth	10.06	3	*
very shiny/shiny/dull/very dull	10.85	3	*
bioerosion: none/some/extensive	17.50	2	**
encrustation: none/some/extensive	1.99	2	not significant

anassid area, as hypothesised. However, other possible explanations for the differences between the two areas should first be discounted, such as physical conditions of the environments including light levels (e.g., Tudhope and Risk, 1985; Scoffin, 1992), hydraulic regime (e.g., Aller, 1982; Scoffin, 1992), and infaunal bivalve ecology and productivity.

The difference in water depth between the two areas is only 4 m (the alpheid area is at c. 6 m and the callianassid area at c. 10 m water depth). Over this depth range, light attenuation is likely to be negligible and the potential amount of microbioerosion by algae approximately the same. As for hydraulic regime, the two areas are only c. 20 m apart and diver observation suggests that they experience similar energy levels, with respect to currents and wave action. Therefore, variation in energy cannot be used to explain differences in levels of physical abrasion. The lack of effect of physical disturbance is supported by the differences in shell signatures caused by the two shrimp taxa.

It is concluded that the rate of addition of new individuals to the infaunal bivalve population is not an important factor when comparing the two areas. Differences in supply rates of fresh bivalve shells to the sediment also could influence the number of pristine grains in the cores (Swinchatt, 1965; Scoffin, 1992). However, the two areas are only meters apart and have similar concentrations of dead bivalve shells; if anything, there are fewer shells in the callianassid area. If this slight difference in abundance was due to supply, it would suggest that the callianassid area had a lower productivity and, thus, lower numbers of pristine grains. However, this is not the case (Fig. 4).

A more convincing explanation in the differences in levels of degradation of gravel-sized grains is the differences in bioturbation between the two areas (Fig. 3). The reasons for this difference could be related to the variation in residence time of shells near the surface and/or the manner in which the shells are handled by the shrimps.

TABLE 4—Estimated turnover rates for callianassid and alpheid shrimps. Values for the whole sediment and >4-mm fraction are shown. Rates in units per m^2 are calculated from burrow densities measured during transect surveys.

		Alpheid	Callianassid
Turnover rate for all sediment	($kg\ burrow^{-1}\ yr^{-1}$)	33.8	99.3
	($kg\ m^{-2}\ yr^{-1}$)	4.5	23.8
% of grains >4mm		10.93	1.74
Turnover rate for >4mm fraction	($kg\ burrow^{-1}\ yr^{-1}$)	3.69	1.73
	($kg\ m^{-2}\ yr^{-1}$)	0.49	0.41

Amount of Time Exposed to Surface Processes

Alpheids turn over the coarse fraction more quickly than do callianassids (Table 4) and, although they bury grains and thereby slow or stop taphonomic alteration, the same grains frequently are re-excavated and redeposited at the sediment surface, thus restarting the degradation. Hence, in sediments inhabited by alpheids, bivalve shells have a good chance of being reworked to the surface and repeatedly being exposed to surface processes, thereby lowering their preservation potential (see also Martin et al., 1996).

In contrast, infaunal bivalve shells in an area burrowed by callianassids may never reach the sediment surface due to rapid and deep burial within the callianassid burrow below the TAZ (see also Aller, 1982; Tudhope and Scoffin, 1984; Tudhope and Risk, 1985; Scoffin, 1992). Coarse grains are concentrated at depth by the repeated transfer of fine grains to the surface ('conveyor-belt feeding'; Rhoads and Stanley, 1965; Meldahl, 1987). Buried grains suffer less degradation than those in the alpheid area, and have a better preservation potential. The pockets where the shells are stored are often full of black organic matter, and/or are sealed off from the rest of the burrow; hence, it is likely that they experience anoxic conditions. Anoxia is related to increased alkalinity (Fig. 1) and this, in combination with any buffering that may occur in the packed clusters of carbonate grains, further increases the preservation potential of these grains.

Callianassids do not, therefore, fit into the general assumption that burial by bioturbation is a slow process that allows a substantial amount of time for grains to be degraded (e.g., Cummins et al., 1986; Davies et al., 1989b). In fact, they enhance the chances of carbonate preservation by burying the grains nearer the base of the TAZ and, thus, decrease their chances of physical reworking. This is consistent with the findings of Tudhope and Scoffin (1984), Flessa et al. (1993), and Martin et al. (1996).

Amount of Abrasion as a Result of Handling by Crustaceans

Faster turnover rates, combined with the shovelling technique used by alpheids to move grains of all sizes, may result in more abrasion as grains are rolled over and rub against each other, especially if the grain surfaces already are weakened by dissolution or microboring. Callianassids move larger grains smaller distances than alpheids, and move them less often.

Variation Between Cores

Due to the fragmentation and degradation of most of the bivalves in the cores analysed, identification of species was impossible. Hence, the fragments examined will have been derived from a range of bivalve species. Different species have different shapes, thicknesses, sculptures, and mineralogy, all of which will affect the rate at which they are degraded (Flessa and Brown, 1983; Callender et al., 1994). They also may have been transported from other environments during storms. In addition, although obvious reef-dwelling species such as oysters and coral borers were removed from these cores and not analyzed, it is inevitable that unidentifiable fragments of epifaunal species will have been included. These species are likely to have been degraded while still alive on the reef and during their transport from the reef to the sediment. However, this variability, together with any small-scale variability in taphonomic processes (Callender et al., 1994), does not detract from the significant differences seen between grains from the two areas burrowed by different crustaceans.

Effect of Grain Size

This paper investigates only gravel-sized debris, but it is worth considering the fate of finer sediment fractions. In an alpheid area, all sediment of all sizes gets turned over indiscriminately, thus exposing it all to the same amount of erosion at the surface. However, in the callianassid area, it is only the fine (approx. <2 mm) grains that are brought to the surface and exposed to relatively more erosion (taphonomic tiering; Walker and Goldstein, 1999). Thus, the fines will get finer and the coarse fraction will be preserved, as found by Martin et al. (1996) for foraminifera (small grains) and bivalves (large grains) in Mexico.

In Phuket, the sediments are mineralogically heterogeneous, comprising reef- and infauna-derived skeletal carbonates and non-carbonate material of terrestrial origin. The coarse fraction is predominantly biogenic carbonate fragments (e.g., >5-mm fraction is 98% CaCO₃), whereas the finer fractions are a mixture of carbonate and terrigenous muds.

Biogenic sorting with respect to grain size, therefore, indirectly sorts with respect to grain type. Because carbonate grains are more susceptible to breakdown by microbioerosion and abrasion than non-carbonate grains, a bioturbated surficial fine layer (such as in the callianassid area) will become increasingly rich in terrigenous material as the carbonate grains are broken down and exported.

Implications for Taphofacies Interpretation

Buried bioclasts potentially can record their habitat (Davies et al., 1989a) and/or their preservational environment (taphofacies; e.g., Speyer and Brett, 1986; Cutler, 1995; Kowalewski and Flessa, 1995; Martin et al., 1996). However, like studies by Flessa et al. (1993) and Martin et al. (1996), this study shows that, even on the small scale of tens of meters, preservational conditions may be very different and, hence, care must be taken in taphofacies interpretation.

The taphonomic bias resulting from these crustaceans' activities will affect the nature of the fossil reefal record.

In the alpheid area, all coarse grains will show various states of degradation, the sediment is likely to be finer overall than the callianassid area, and sorting will be poor. This will make an alpheid area difficult to interpret as being a reefal area. In an area that has been burrowed by callianassids, both infaunal and reefal coarse material (if supplied to the area) will be well preserved, and the finer sediment will have been broken down into progressively finer material and may have been exported. Thus, the mean grain size of the sediment may be coarser and sorting better than the alpheid area sediments. The presence of well-preserved coarse fragments will ease interpretation as a reefal environment.

The rapid burial of grains also has implications for time-averaging of sediments. With processes such as rapid burial occurring, a shell's surface condition will not be indicative of its age, but rather its residence time at the surface-water interface (Flessa et al., 1993; Martin et al., 1996).

CONCLUSIONS

Gravel-sized, calcareous bivalve fragments are better preserved in areas of callianassid bioturbation than in those inhabited by alpheid shrimps. This is due to the repeated exposure of grains of this size to surface processes in the area burrowed by alpheids and the burial of this size fraction at sediment depths of >25 cm by callianassids. The different degrees of abrasion experienced due to the different types of bioturbation also plays a part. Thus, despite close spatial proximity and identical hydraulic regimes, the sediment textures are very different.

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