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ABRASION-RESISTANCE OF MODERN REEF-DWELLING FORAMINIFERA FROM DISCOVERY BAY, JAMAICA -- IMPLICATIONS FOR TEST PRESERVATION

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ABSTRACT

The effects of taphonomic processes on common foraminiferal species from the tropical carbonate shelf environment at Discovery Bay, Jamaica were investigated to determine their role in the formation of foraminiferal sediment assemblages. The fringing coral reefs at Discovery Bay, Jamaica exhibit a distinctive depth-related gradient in water turbulence and the associated taphonomic factor of abrasion, thus providing an ideal setting for this study. Examination of the preservation potential of common foraminiferal species allowed for the testing of the taphofacies model proposed by Liddell and Martin (1989). These taphofacies correspond primarily to reef physiographic zones and associated depth-related taphonomic gradients. Identification of taphonomic signatures on the specimens may be indicative of depositional environments (i.e., high or low energy).

No taxonomic bias in susceptibility to abrasion was evident in the taxonomic groups of foraminifera employed (suborders Miliolina, Textulariina and Rotaliina (benthic and planktic); thus, no one suborder was preferentially destroyed by abrasion. Abrasion-resistance seems to depend on a combination of test characteristics (test shape, size, wall thickness and microstructure), with no one characteristic controlling the degree of damage. Although most species tested in this study display high preservation potential in abrasion-resistance, relative abrasion-resistance of species may be useful in defining the relative amount of taphonomic processes in fossil assemblages by noting the less resistant forms found. Sediment assemblages in turbulent environments should become enriched with abrasion-resistant forms. Analysis of the susceptibility of tests to taphonomic processes may indicate the influence of ecologic and taphonomic constraints on test morphology and preservation through time.

INTRODUCTION

Taphonomic processes are integral factors in the formation of sedimentary deposits. Taphonomic processes produce biases that may either enhance or obscure information recorded in paleocommunities and evolutionary lineages (Kidwell, 1986; Kidwell and Behrensmeyer, 1988), thus providing an incomplete picture of life assemblages or environments (Chave, 1960). Studies of microfossil taphonomy may not only document information loss, but may also provide information in the interpretation of community paleoecology (Johnson , 1960). The determination of test characteristic morphotypes which resist destruction may also have important evolutionary implications, and should lead to a better understanding of the morphological constraints on species inhabiting particular environments (Wetmore, 1987). Unfortunately, studies of microfossil taphonomy are limited, particularly those studies addressing benthic foraminiferal taphonomy. The majority of taphonomic studies of marine organisms have

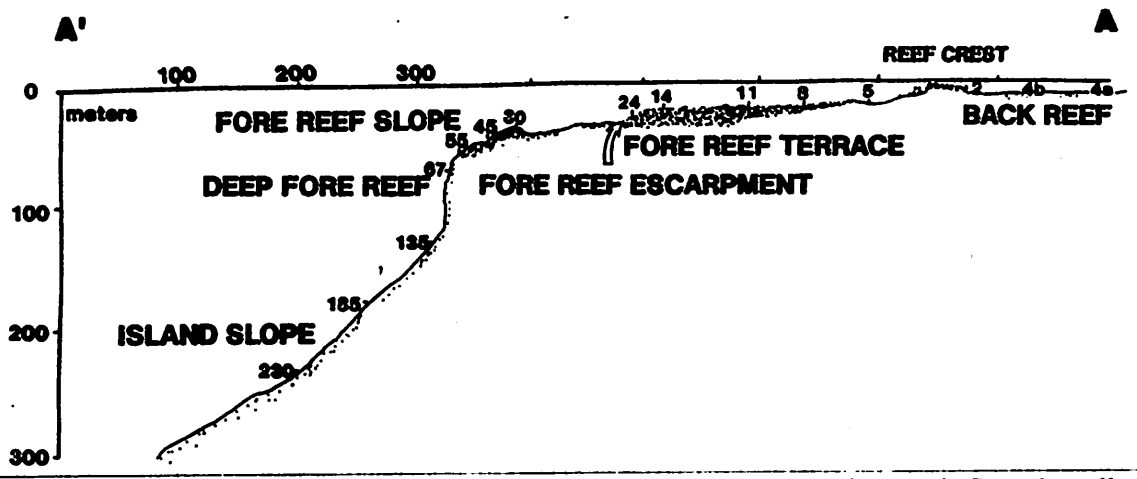


Fig. 1. Profile of Discovery Bay Jamaica sampling traverse A - A' (= Zingorro). Sample collection sites are indicated with depth, in meters, of location. The profile represents a physical gradient in water energy (back reef: low; fore reef terrace: high; fore reef escarpment: low; fore reef slope, deep fore reef and island slope: low) and associated taphonomic processes.

SPECIES	SUBCLASS	MICROSTRUCTURE	SHAPE	WALL THICKNESS	SIZE	REEF ZONE HABITAT
Archaias angulatus	Rotaliina	calcareous, imperforate	lenticular	thin, but reinforced by pillars	small - large (0.5 - 2.0 mm)	dominant in back reef
Amphistegina gibbosa	Miliolina	calcareous, perforate	lenticular	thick	small - large (0.5 - 2.0 mm)	dominant on fore reef terrace
Asterigerina carinata	Rotaliina	calcareous, perforate	conical	thick, with heavy umbilical plug	small (< 0.5 mm)	common on fore reef terrace
Bigenerina irregularis	Textulariina	agglutinated	curvilinear	thin, lightly cemented	small - large (0.5 - 1.0 mm)	common on fore reef slope
Cyclorbiculina compressa	Miliolina	calcareous, imperforate	discoidal	thin, but reinforced by pillars	small - large (>0.5 - 2.0 mm)	most abundant in back reef
Discorbis rosea	Rotaliina	calcareous, perforate	spherical	thick	small (< 0.5 mm)	most abundant on fore reef slope
Globigerinoides quadrilobatus	Rotaliina	calcareous, perforate	globular	thin, fragile	small - medium (< 0.5 - 1 mm)	most abundant on fore reef slope and deeper environments
Planorbulina acervalis	Rotaliina	calcareous, perforate	discoidal	thin, fragile	medium - large (>0.5 - 1 mm)	common in back reef
Peneroplis proteus	Miliolina	calcareous, imperforate	discoidal	thin	small - large (0.5 - 2.0 mm)	common in back reef
Quinqueloculina lamarckiana	Miliolina	calcareous, imperforate	spindle	thick	medium - large (>0.5 - 1.0 mm)	ubiquitous back reef-fore reef slope
Quinqueloculina tricarinata	Miliolina	calcareous, imperforate	spindle	thick	medium - large (>0.5 - 1.0 mm)	fore reef slope
Sorites marginalis	Miliolina	calcareous, imperforate	discoidal	thin, fragile	medium - large (>0.5 - 1.0 mm)	common in back reef

TABLE 1. Foraminiferal species selected for taphonomic analysis. Species were selected on the basis of abundance, wall type, shape and size so as to utilize a diversity of forms. All species are benthic, except for *Globigerinoides quadrilobatus*, which is planktonic.

dealt with macroinvertebrates (for example see Chave, 1964; Driscoll, 1967; Driscoll and Weltin, 1973). Foraminiferal distributional studies have been conducted emphasizing growth rates (Hallock, 1979), sediment production (Muller, 1974; Boss and Liddell, 1987a; 1987b) and foraminiferal population dynamics (Hallock, 1980; 1984; Scott and Medioli,1980) as controlling factors. Taphonomy, on the other hand, has been little studied as a major control on the formation of foraminiferal assemblages (but see Smith, 1987; Cottey and Hallock, 1988; Martin and Wright, 1988; Peebles and Lewis, 1989). Fossil assemblages of foraminifera may be modified by a variety of factors. One of the most significant factors in test reduction is destruction by abrasion (Driscoll and Weltin, 1973; Cottey and Hallock, 1988).

Modern carbonate environments provide ideal settings for the evaluation of the effect of taphonomic processes on the formation of foraminiferal fossil assemblages because of pronounced depth-related gradients in water turbulence and associated taphonomic gradients in post-mortem abrasion (Liddell and Martin, 1989). Liddell and Martin (1989) present a foraminiferal taphofacies model for Jamaican north coast fringing reefs and associated lagoonal and basinal environments. The model is based upon the known distribution of environmental energy and reef physiography (Liddell *et al.*, 1987). Bathymetric trends in foraminiferal diversity (Martin and Liddell, 1988) and known distributions of particular taxa in sediment assemblages (Martin and Wright, 1988) support the model Fig.1.

The objective of this study was to illustrate the effects of abrasion on the tests of common foraminifera (Table 1) from a tropical carbonate shelf environment at Discovery Bay, Jamaica (Fig. 2). A number of the species used in this study have already been utilized in the delineation of detailed foraminiferal biofacies (Martin and Liddell, 1988) along a depth-related gradient of taphonomic factors (wave energy, abrasion, etc.) (Liddell and Martin, 1989).

AREA OF INVESTIGATION

Discovery Bay, Jamaica is located on the north central coast of the island at Latitude 18°33'N and Longitude 77°20'W (Figs. 2A and B). The fringing coral reefs and associated environments at Discovery Bay exhibit a distinct depth-related gradient (Fig. 1) in physical parameters (i.e. water turbulence, wave energy) and associated taphonomic factors (Liddell and Martin, 1989), thus providing an ideal setting for this study.

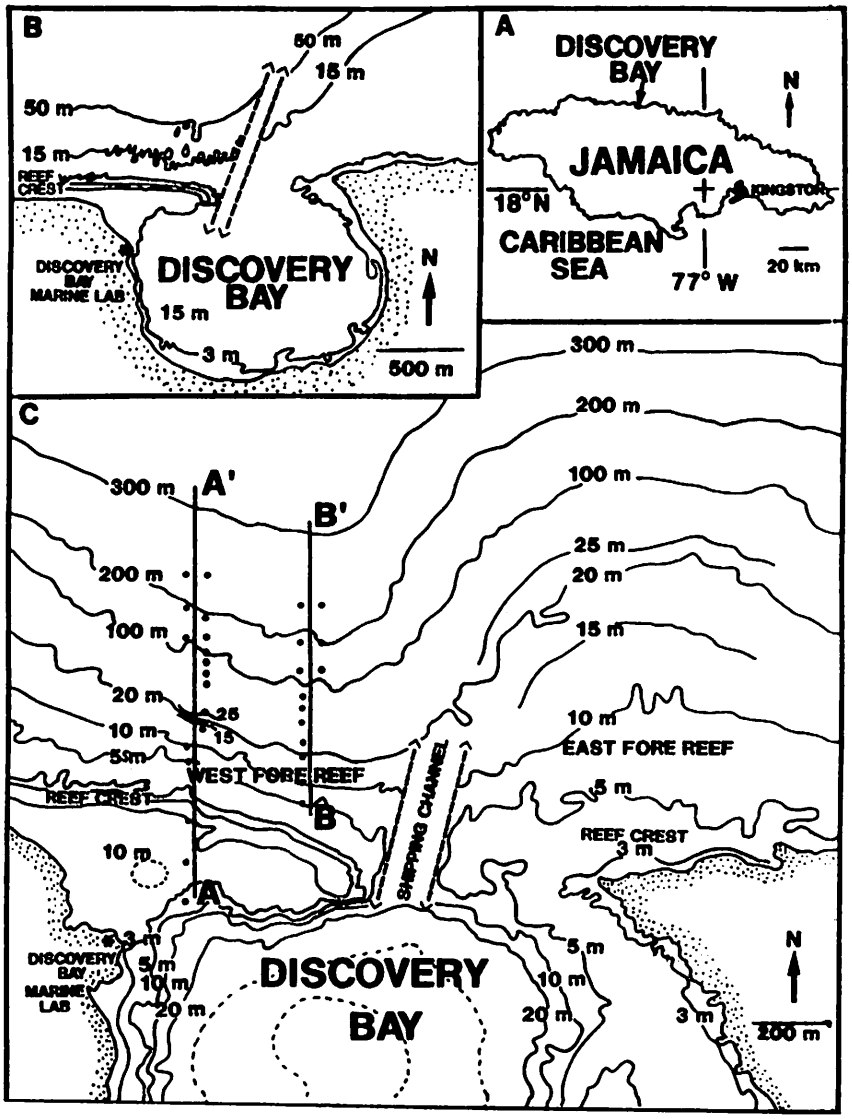


Fig. 2. Index map of Discovery Bay, Jamaica. A. Map of Jamaica indicating the location of Discovery Bay. B. Map of the Discovery Bay region. Modified from Liddell and Ohlhorst, 1981. C. Map of Discovery Bay showing bathymetry and sampling traverses A - A' (= Zingorro) and B - B' (= LTS). · indicate sampling sites used in this and previous studies. Modified from Martin and Liddell, 1988.

The transects (A - A', B - B'; Fig. 2) sampled for this study lie on the West Fore Reef of Discovery Bay on fringing reefs known as 'Zingorro' and 'LTS', respectively. The West Fore Reef exhibits the structural/physiographic zones which are characteristic of most Jamaican north coast reefs (Goreau and Goreau, 1973; Liddell and Ohlhorst, 1981). The reef physiographic zones encountered along the onshore to offshore sampling transect (Fig. 2) are respectively: back reef, reef crest, fore-reef terrace, fore-reef escarpment, fore-reef slope, and upper deep fore-reef.

METHODS OF INVESTIGATION

Field Methods

Sediment samples were previously collected along traverses crossing the West Fore Reef of Discovery Bay (A-A' = Zingorro and B-B' = LTS) (Fig. 1). Sediment cores (approximately 5 cm diameter x 5 cm length; approximately 100 cm^3 volume) were collected from each of the physiographic reef zones (see Fig. 1) using SCUBA in August, 1983. Fore reef samples were collected from reef spurs (buttresses) and lobes and deep fore reef samples were collected from sediment trapped by ledges on the vertical escarpment of the deep fore reef. After collection the sediment samples were dried at low temperature (approximately 28°C) to retain shell strength (Martin and Liddell, 1988).

Laboratory Methods

Specimen Selection.

Species were chosen for experimental analyses based primarily on their abundance in the Jamaican fauna. In addition to abundance, species were selected based on their morphology (i.e. perforate, imperforate, thick-walled, thin-walled, lenticular, conical, etc.) to provide a diverse array of morphotypes. Based on the aforementioned criteria, twelve foraminiferal species were chosen (Table 1). In addition, the calcareous alga *Halimeda* was chosen for analysis as it is a major contributor to the carbonate sediment. Specimens were selected from the 0.5 - 1.0 mm size class in which most species were most common. Specimens of *Discorbis rosea* and *Asterigerina carinata* were chosen from the 0.25 - 0.5 mm size fraction because they are most common in this size interval. Size control was used in order to avoid bias that could result from 1) differences in size frequency distributions among samples and 2) differential rates of destruction related to test size (Cottey and Hallock, 1988). Specimens showing little or no taphonomic alteration (i.e. obliterated ornamentation, shallow cracks, impact depression or pitting, scalloping of margins, breakage) were picked from the sediment samples under a binocular microscope.

Abrasion Experiments.

Ten "taphonomically unaltered" specimens of each species group were picked from the sediment samples for abrasion analyses. All specimens were photographed, in full view and close-up, prior to experimentation (0 Hour) with a Cambridge 150 Model Stereoscan 90B Electron Microscope. The specimens were then placed in containers believed to simulate the shifting bottom sediments of the reef environment. The containers each held approximately 7 grams of carbonate sediment. The sediment was standardized to approximately 0.5 mm (approximate mean grain size range of the Jamaican fore reef; Liddell *et al.*, 1987), and had been picked of all identifiable foraminifera, so that the specimens being tested could be differentiated from the carbonate sediment. The sediment and specimens were submersed in 20 ml of Instant Ocean^R Synthetic Sea Salts (Aquarium Systems, Mentor, Ohio), a buffered solution that has been shown to retain a pH of 8.0 when combined with the carbonate sediment for a length of time. This volume was determined to be sufficient to immerse the sediment and specimens in solution while not too large to decrease the chance of grain to grain contact. The solution remained at room temperature (approximately 23-24°C). Specimens were evacuated of air prior to experimentation in order to permit filling of test voids and chambers with solution to prevent flotation.

The containers were then secured on a Lab-Line Orbit Shaker shaking apparatus and rotated at 150 rpm. This speed maximized grain to grain contact, while minimizing grain suspension. After 125 hours of shaking, the specimens were removed from the container and remounted, photographed and cleaned as described below. The samples were then returned to the container and the procedure repeated after 250 hours, 500 hours and 1000 hours of shaking. The hours of shaking are cumulative; i.e., 250 hours of shaking was 125 hours after the already

SPECIES	A % AREA AFFECTED BY TAPHONOMIC PROCESSES AFTER 1000 HOURS (see Appendix E)	RANK of A	B % INITIAL POPULATION DESTROYED BY TAPHONOMIC PROCESS (see Appendix A)	RANK of B	C ABRASION INDEX (A x B)	RANK of C
Archaias angulatus	15 ± 8	4.5**	0	3	13.5	2
Amphistegina gibbosa	81 ± 34	11	0	3	33	6
Asterigerina carinata	100 ± 0	13	50	11	143	13
Bigenerina irregularis	16 ± 18	4.5	12	6	27	4
Cyclorbiculina compressa	83 ± 28	11	0	3	33	6
Discorbis rosea	38 ± 48	7.5	17	7	52.5	10
Globigerinoides quadrilobatus	11 ± 22	4.5	33	10	45	9
Planorbulina acervalis	5 ± n/a*	1.5	100	13	19.5	3
Peneroplis proteus	10 ± 3	4.5	28	9	40.5	8
Quinqueloculina lamarckiana	60 ± 44	9	22	8	72	11
Quinqueloculina tricarinata	3 ± 6	1.5	0	3	4.5	1
Sorites marginalis	45 ± 42	7.5	80	12	90	12
Halimeda	70 ± 45	11	0	3	33	6

TABLE 2. Abrasion rankings. The higher the rank of the species, the greater its susceptibility to abrasion. The rankings are according to: A) the percent of specimen area affected by taphonomic features after 1000 hours of abrasion; B) the percentage of specimens experiencing total destruction to taphonomic processes at the end of 1000 hours of abrasion; and C) the value of the abrasion index assigned to the species. In an attempt to give an overall ranking of the species, an abrasion index value was calculated by multiplying the values A and B described previously. * = Only fragments of *Planorbulina acervalis* remained, thus no standard deviation of area affected could be calculated. ** = Rankings are according to Mann-Whitney U for tied ranks.

sampled 125 hours. Using the same specimens continually throughout experimentation allowed for accurate descriptions of the changes encountered during the abrasion runs.

In order to quantify the distance travelled during the abrasion experiment, specimens of varying sizes and shapes were monitored on the shaking table running at 150 rpm. To represent an array of sizes and shapes, *Halimeda* platelets (very large), *Amphistegina gibbosa* (large and lenticular), *Sorites marginalis* (medium and discoidal) and *Discorbis rosea* (small and spherical) were used. A specimen of each was monitored on the shaker table for three different experimental runs (duration of each was one minute). The number of rotations around the container for each specimen was counted for each test run. One rotation around the container is the equivalent of 15 cm. An average distance travelled was then calculated for each species to give a range for the varying sizes and shapes.

In order to combine the effects of abrasion with the other significant taphonomic process of dissolution, the foraminiferal specimens and the algal platelets were subjected to a period of dissolution in a recirculating seawater table (pH = 7.7; 23° C). The specimens were retrieved after 2000 hours and photographed and placed in the shaking containers and then subjected to the abrasion process for a duration of 250 hours.

SEM Photograph Digitization.

The photographs from the 0, 250, 500, and 1000 hour sampling intervals of the abrasion experiments were digitized using a Numonics Digitizer. The cross-sectional area of the specimen was measured by using the digitizer to follow the perimeter of the specimen as seen in the full-view SEM photographs. Taphonomic features of abrasion were categorized into 1) deep pits - impact depressions that breach the test wall to expose inner chambers; 2) shallow pits - impact depressions that do not breach the test wall; 3) breakage - regions of the specimen that are missing large portions of the test; 4) scalloping - margins of the test are scalloped; 5) cracks - fractures on the surface of the test; and 6) other. The "other" category includes obliteration of apertures, loss of detail of sutures, removal of outer calcite layer and exposure of chambers (Plate 1). These features, with the

exception of shallow cracks, were measured in the same format as the entire area of the specimen. The cracks were measured using a line intersection method detailed by Mark (1974) for calculating drainage density of streams. All measurements were made in square millimeters. For each specimen of a given species, the percentage of total specimen area affected by each taphonomic feature (deep pits, shallow pits, breakage, scalloping, cracks and other), as well as the sum of these features (total), were calculated. The calculations were made on the specimens remaining at that given time interval. The percent of the initial population destroyed by taphonomic processes (complete obliteration) was noted throughout experimentation (see Table 2).

RESULTS

Representative specimens from four of the thirteen species analyzed are illustrated in Plates 2 - 5 (*Archaias angulatus*, *Amphistegina gibbosa*, *Bigenerina irregularis*, and *Sorites marginalis*). Each plate depicts the same specimen of a given species initially (0 Hour) and after 250, 500 and 1000 hours of abrasion. Results of the abrasion experiment indicate that the common foraminiferal species of Discovery Bay, Jamaica and the calcareous alga *Halimeda* have varying susceptibilities to abrasion. Eight of the thirteen species lost at least 10% of the original population (10 specimens) presumably due to taphonomic processes (complete obliteration), of which three (*Asterigerina carinata*, *Planorbulina acervalis*, and *Sorites marginalis*) lost ≥50%.Measurements of the specimen areas affected by the taphonomic features (deep pits, shallow pits, etc.) show an increase in area affected over time.

Ranking of the species at each time interval according to the total percent of area affected, from low to high, indicates no significant difference among species in susceptibility to abrasion through time (Mann-Whitney U for tied ranks; $\alpha < 0.05$). That is, the species least affected after 250 hours of abrasion were also the least affected after 500 and 1000 hours. And the species with the highest percent of total area affected by taphonomic features after 250 hours of abrasion remained the most affected after 500 and 1000 hours.

Comparison of the percent of specimen area affected after 1000 hours of abrasion with the percent loss of specimens to taphonomic processes after 1000 hours also presents no significant difference among species (Mann-Whitney U for tied ranks; $\alpha < 0.05$). That is, the species with the highest percent area affected by taphonomic features are the species with the highest percent loss of specimens to taphonomic processes (total obliteration). Table 2 displays the 12 species of foraminifera analyzed in the study, along with *Halimeda*, and their rankings according to: A) the percent of specimen area affected by taphonomic features after 1000 hours of abrasion; B) the percentage of specimens experiencing total destruction to taphonomic processes at the end of 1000 hours of abrasion; and C) the value of an "abrasion index" assigned to the species, which represents an attempt to give an overall ranking of each species to abrasion resistance. Comparison of the rankings (Table 2) with test features (Table 1) indicates that robust tests with large surface area (i. e., *Discorbis rosea*, *Archaias angulatus*, and *Amphistegina gibbosa*) survived experimentation with little or no damage. Meanwhile, small and/or fragile tests with small surface area (*Asterigerina carinata*, *Planorbulina acervalis*, and *Sorites marginalis*) were highly damaged or destroyed.

Many attempts at achieving an overall ranking were tried, with basically the same results. The two values, A and B, were multiplied so that the weight of one would not be stressed over the other. Mann-Whitney U for tied ranks of A vs. B, A vs. C and B vs. C indicate no significant difference ($\alpha < 0.05$) in the

SPECIES	ROTATIONS/MINUTE				x 15 cm/rotation	AVERAGE DISTANCE TRAVELLED IN KILOMETERS		
	R1	R2	R3	R AVG		250 hr	500 hr	1000 hr
Halimeda	44	47	50	47 ± 3	705 ± 45 cm/min	106 ± 7	212 ± 14	425 ± 28
Amphistegina gibbosa	37	51	45	44 ± 5	660 ± 75 cm/min	99 ± 11	198 ± 22	396 ± 44
Sorites marginalis	36	45	28	36 ± 7	540 ± 105 cm/min	81 ± 15	161 ± 30	324 ± 60
Discorbis rosea	24	32	26	27 ± 3	405 ± 45 cm/min	60 ± 7	121 ± 14	243 ± 28

TABLE 3. Distance travelled through time. Values are based on the average number (n = 3) of rotations for each species around the container during experimental runs of one minute duration. The shaker table was operating at 150 rpm. One rotation is equivalent to 15 cm.

basis for the ranking of the species. A noticeable exception in ranking is the position of *Planorbulina acervalis*. The percent area affected by taphonomic processes measured for *Planorbulina acervalis* was based on the few fragments that remained for this species. The fragments were small, with not much area affected (5%), while the percent specimen total destroyed is valued at 100% as the fragments were not identifiable to the original population of specimens. *Amphistegina gibbosa*, *Cyclorbiculina compressa* and *Halimeda* tied in their overall values for ranking. The ranking of the species reveal no taxonomic bias in susceptibility to abrasion or in the taphonomic features produced. No one suborder (Miliolina, Textulariina, Rotaliina) was more susceptible than another.

Pitting, both deep and shallow, was the most common taphonomic featured produced by abrasion in the experiments. Impact depressions were most abundant on the surfaces of *Archaias angulatus* (Plate 2), *Peneroplis proteus* (Plate 1, Fig. 1) and *Sorites marginalis* (Plate 5). The majority of the species were affected by features within the "other" category, with the loss of the outer calcite layer as the dominant member of that category. This feature was identified on specimens of all of the species in the study, with dominance on *Amphistegina gibbosa* (Plate 3), *Asterigerina carinata* (Plate 1, Fig. 7), *Cyclorbiculina compressa*, *Discorbis rosea* and *Halimeda*. Fragile tests of *Globigerinoides quadrilobatus* (Plate 1, Fig. 2), *Planorbulina acervalis* , and *Quinqueloculina lamarckiana* (Plate 1, Fig. 3) experienced a large amount (up to 15% of the test area) of breakage. Scalloping was most frequent on tests of *Archaias angulatus* (Plate 2) and *Peneroplis proteus* (Plate 1, Fig. 1). Cracks covered up to 10% of test area on *Amphistegina gibbosa* (Plate 3) and *Quinqueloculina lamarckiana* (Plate 1, Figure 3).

Table 3 represents the results of the experiment to quantify the distance travelled by the foraminifera on the shaker table operating at 150 rpm during the abrasion experiment. The range of sizes and shapes of foraminifera tested (Table 1) give a range of 243 - 425 km travelled during 1000 hours. This may be compared to the values calculated by Peebles and Lewis (1989) for distance travelled in a tumbler, rather than on a shaker table. Peebles and Lewis (1989) cite a range of 34 - 100 km of movement in 2000 hours of tumbling. This is equivalent to 17 - 50 km of movement in 1000 hours, values 8.5 - 14 times less than distances calculated in this experiment.

Based on the data from Table 3, the simulated time of agitation at Discovery Bay, Jamaica was calculated. An average distance travelled in 1000 hours of 347 km was used for the calculation. Assuming that a particle travelling in bidirectional surge currents at 15 m depth will travel 0.125 m onshore and 0.125 m offshore, a particle will potentially travel 0.250 m per wave. With an assumed wave period of 30 seconds, 0.5 m of travel per minute = 76.65 km of travel per year (assuming 7 hrs/day of wave activity; Discovery Bay Marine Lab wind records indicate strong wave activity at Jamaica occurs from approximately 10 - 11 A.M. to 5 - 6 P.M.). Therefore, 1000 hours on a shaker table (347 km travel) = 5 years at 15 m at Discovery Bay, Jamaica. This is a rough estimate and is considered by the authors to be too high, and an estimate of 0.5 years at 15 m would be a closer representation of 1000 hours on the shaker table operating at 150 rpm.

Combining the effects of dissolution in the sea-water table and abrasion display different results than when abrasion was the solitary taphonomic agent. Chemical degradation by dissolution greatly weakened nonresistant tests, thus causing higher susceptibility to abrasion in otherwise abrasion resistant tests. Tests of *Bigenerina irregularis*, *Globigerinoides quadrilobatus*, *Peneroplis proteus*, and *Quinqueloculina lamarckiana* survived 1000 hours of abrasion, yet were 80 - 100% completely obliterated after 250 hours of abrasion subsequent to 2000 hours of dissolution in the seawater table. Other species (i.e. *Amphistegina gibbosa*, *Cyclorbiculina compressa*, *Planorbulina acervalis*, *Sorites marginalis*) show little affect by dissolution. The effects of abrasion after dissolution were the same in the absence of the dissolution factor. These species were no more susceptible to abrasion with dissolution as an altering agent than without.

DISCUSSION

The foraminifera of Discovery Bay, Jamaica differ in their relative resistance to abrasion in medium-sized carbonate sand, albeit slightly. After 1000 hours of abrasion in controlled laboratory experiments, only 26% of the laboratory assemblage was destroyed by abrasion

PLATES

PLATE 1. TAPHONOMIC FEATURES OF ABRASION: Plate 1 illustrates the different taphonomic features produced by abrasion that were identified in this study. See text for explanation of the features. Each figure (except Figure 3) depicts the same specimen at two different time intervals as indicated in the plate explanation.

FIGURE 1. DEEP PITS, SHALLOW PITS, SCALLOPING. *Peneroplis proteus*. A. An initial specimen (0 Hour). Scale 500 μm. B. 1000 Hour specimen showing signs of taphonomic alteration. a - deep pits. b - shallow pits. c - scalloping. Note decrease in size due to outer chamber being broken away. Scale = 500 μm.

FIGURE 2. BREAKAGE. *Globigerinoides quadrilobatus*. A. An initial specimen (0 Hour). Scale = 500 μm. B. 1000 Hour specimen showing signs of taphonomic alteration. a - breakage. Scale = 500 μm.

FIGURE 3. CRACKS. *Quinqueloculina lamarckiana*. A. A specimen after 125 hours of abrasion showing fracturing of the test wall. a - cracks. b - cracks. Scale = 500 μm. B. An enlargement of b at 3000 x. Scale = 10 μm.

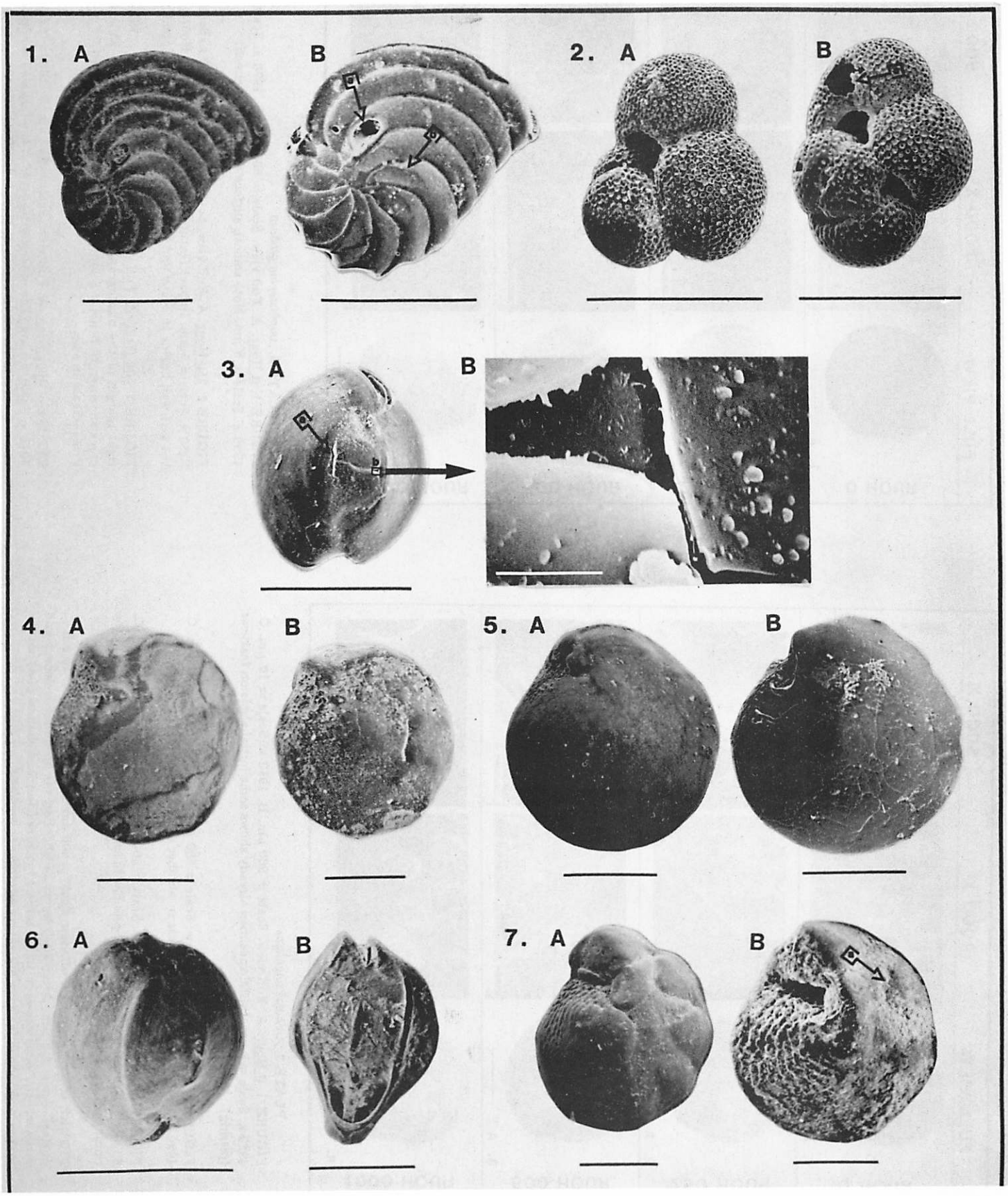
FIGURES 4 - 7. OTHER.

FIGURE 4. REMOVAL OF OUTER CALCITE LAYER. *Amphistegina gibbosa*. A. An initial specimen (0 Hour). Scale = 500 μm. B. 250 Hour specimen showing signs of taphonomic alteration. The outer layer of calcite has been removed. Note coarse texture of test surface in B as compared with relatively smooth surface in A. Scale = 500 μm.

FIGURE 5. OBLITERATION OF APERTURE. *Amphistegina gibbosa*. A. An initial specimen (0 hour). Scale = 500 μm. B. 1000 Hour specimen showing signs of taphonomic alteration. a - the aperture of this foraminifera has been obliterated due to taphonomic processes. Scale = 500 μm.

FIGURE 6. EXPOSURE OF CHAMBERS. *Quinqueloculina lamarckiana*. A. An initial specimen (0 Hour). Scale = 500 μm. B. 250 Hour specimen showing signs of taphonomic alteration. The test wall has been completely removed to expose the inner chambers of the foraminifer. Scale = 500 μm.

FIGURE 7. LOSS OF DETAIL OF SUTURES. *Asterigerina carinata*. A. An initial specimen (0 Hour). Scale = 200 μm. B. 250 Hour specimen showing signs of taphonomic alteration. a - the sutures of the foraminifera are barely visible due to abrasion. Scale = 200 μm.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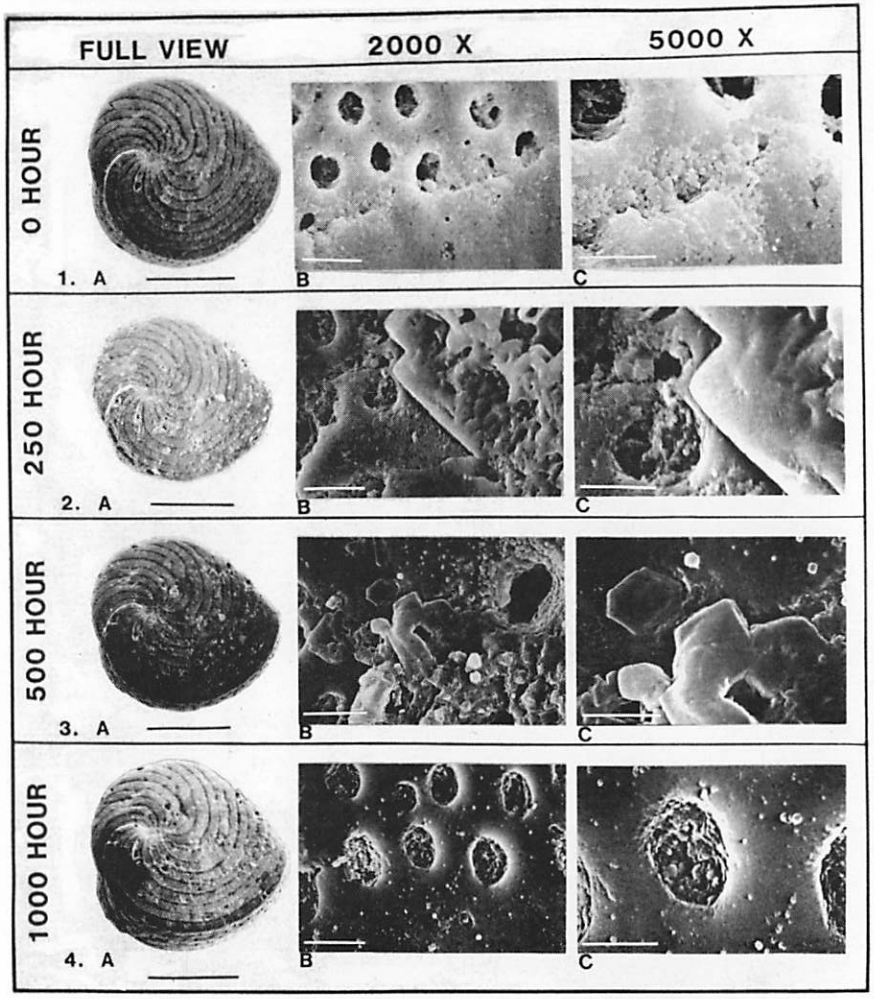

PLATE 2. *Archaias angulatus*

FIGURE 1. 0 Hour. A. Full view. Scale = 500 μm. B. 1950 x. Scale = 10 μm. C. 4920 x. Scale = 5 μm. Initial specimen already shows some initial abrasion features (pitting).

FIGURE 2. 250 Hour. A. Full view. Scale = 500 μm. B. 1970 x. Scale = 10 μm. C. 4920 x. Scale = 5 μm. Note increase in number of pits from 0 Hour.

FIGURE 3. 500 Hour. A. Full view. Scale = 500 μm. B. 2060 x. Scale = 10 μm. C. 5070 x. Scale = 5 μm. Diameter of pits has increased from 250 Hour, as well as the number of impact features.

FIGURE 4. 1000 Hour. A. Full view. Scale = 500 μm. B. 1990 x. Scale = 10 μm.C. 4970 x. Scale = 5 μm. After 1000 hours of abrasion the specimen is intact and relatively the same size as initially. Impact features (deep and shallow pits) are the major taphonomic features appearing on *Archaias angulatus*.

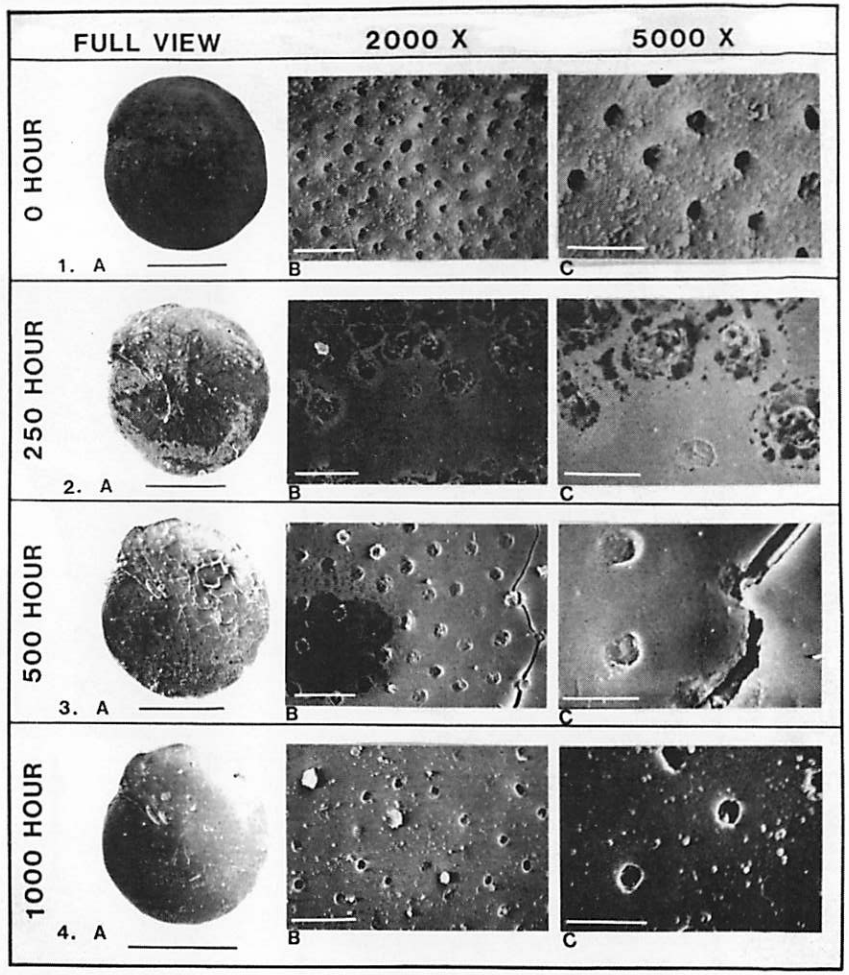

PLATE 3. *Amphistegina gibbosa*

FIGURE 1. 0 Hour. A. Full view. Scale = 500 μm. B. 1970 x. Scale = 10 μm. C. 4990 x. Scale = 5 μm. Note smooth surface of initial specimen.

FIGURE 2. 250 Hour. A. Full view. Scale = 500 μm. B. 2090 x. Scale = 10 μm. C. 5130 x. Scale = 5 μm. Impact features begin to appear at 250 Hours. Fracturing of the test wall begins to occur and the margins are slightly scalloped.

FIGURE 3. 500 Hour. A. Full view. Scale = 500 μm. B. 2000 x. Note crack on the right margin of the photograph. Scale = 10 μm. C. 5070 x. Enlargement of the crack shown in B. Scale = 5 μm. Cracks cover most of the surface of the specimen. Pits increase in size.

FIGURE 4. 1000 Hour. A. Full view. Scale = 500 μm. B. 2080 x. Scale = 10 μm. C. 5070 x. Scale = 5 μm. The outer calcite layer of the test wall is removed as a result of the fractures shown in Figure 3. Note reduction in size.

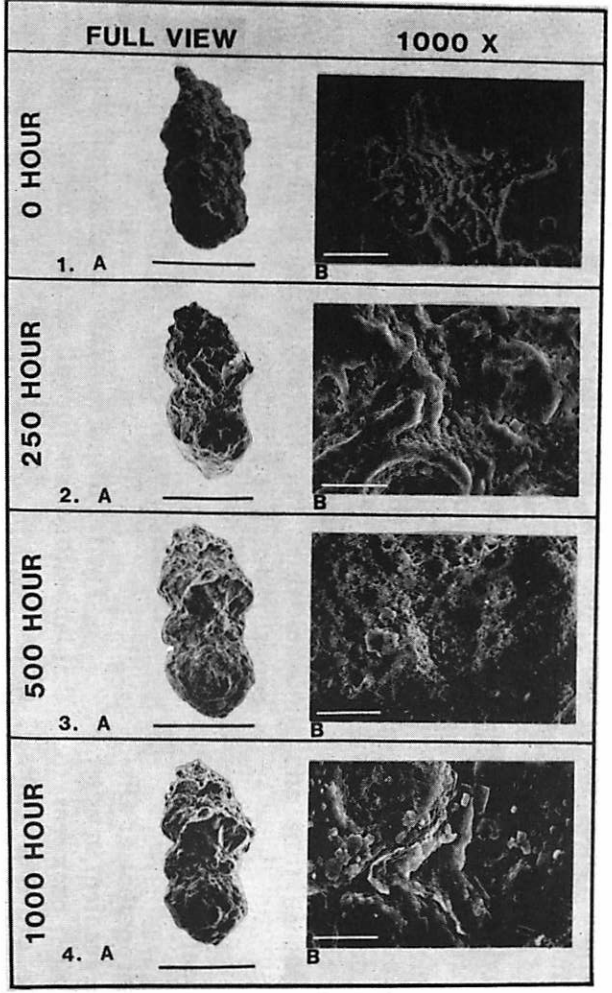

PLATE 4. *Bigenerina irregularis*

FIGURE 1. 0 Hour. A. Full view. Scale = 500 μm. B. 1050 x. Scale = 20 μm. This is the typical appearance of this textulariid in the sediment samples. The surface is rough and hummocky as a result of the agglutination of grains.

FIGURE 2. 250 Hour. A. Full view. Scale = 500 μm. B. 1020 x. Scale = 20 μm. Aperture is broken off after 250 hours of abrasion.

FIGURE 3. 500 Hour. A. Full view. Scale = 500 μm. B. 1010 x. Scale = 20 μm. Grains are abraded and some are removed after 500 Hours.

FIGURE 4. 1000 Hour. A. Full view. Scale = 500 μm. B. 1010 x. Scale = 20 μm. Surface becomes smoother over time as agglutinated grains are rounded during the abrasion process.

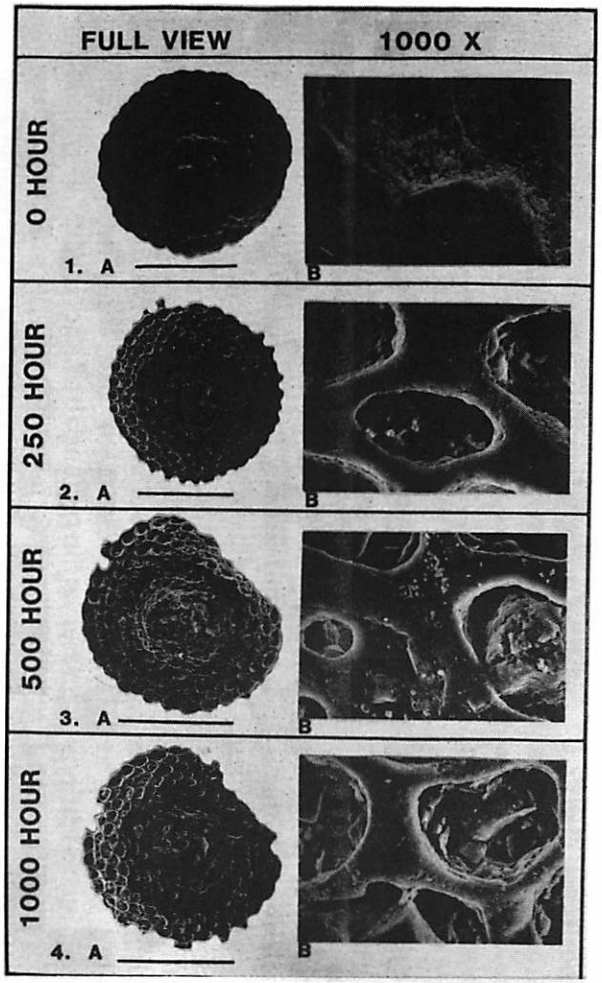

PLATE 5. *Sorites marginalis*

FIGURE 1. 0 Hour. A. Full view. Scale = 500 μm. B. 1010 x. Scale = 20 μm. The only sign of taphonomic alteration of this initial specimen is a deep pit in the center of the test.

FIGURE 2. 250 Hour. A. Full view. Scale = 500 μm. B. 1020 x. Scale = 20 μm. This nonresistant foraminifera is highly altered after 250 hours of abrasion. Deep pits cover a large percentage of surface area of the test. The test surface is polished by the abrasion process.

FIGURE 3. 500 Hour. A. Full view. Scale = 500 μm. B. 1010 x. Scale = 20 μm. Pits increase in size and a large piece of test is broken off causing a great decrease in size.

FIGURE 4. 1000 Hour. A. Full view. Scale = 500 μm. B. 1000 x. Scale = 20 μm. After 1000 hours, the foraminifera is greatly reduced in size and near the point of complete obliteration. The pores are infilled with small grains.

(58% of which were the fragile encrusting species *Planorbulina acervalis* and *Sorites marginalis*). The *Halimeda* platelets showed little degradation by abrasion. The species tested represent a variety of test compositions, size and structure (Table 1). Various methods at achieving an overall ranking gave similar results. No taxonomic bias was evident in the results from any method, although smaller or more fragile tests were preferentially destroyed regardless of taxonomic position.

The question arises as to whether the progressive abrasive destruction of a given foraminiferal species in marine environments is comparable to destruction of the same species under the artificial conditions existing on the shaker table. The artificial conditions induced in the laboratory do, apparently, simulate the abrasion process of the fringing coral reef at Discovery Bay, Jamaica. Similar modifications seen on naturally abraded foraminifera and *Halimeda* platelets in the sediment samples collected for analysis and of those seen on artificially abraded specimens support this conclusion.

Abrasion is not sufficient to destroy foraminifera in low energy environments (i.e. back reef lagoon). In high energy environments (i.e. shallow outer back reef, fore reef terrace), abrasion plays only a minor role (pitted surfaces and impact depressions) in the taphonomic alteration of the foraminiferal assemblages at Discovery Bay, Jamaica. The abrasion textures produced could be useful in determining the relative transport distance and in delineating local environments of deposition. Both the percent of specimen affected and the degree to which the specimens are abraded should be taken into consideration. Peebles and Lewis (1989) state that abrasion can break off large areas of the test, but the process normally acts relatively slowly and it more frequently polishes the surface without causing extensive damage. Thus, as abrasion is not usually rapid or complete, it may be a useful indicator of residence time and transport distance.

Taphofacies Model

The fringing reef environment at Discovery Bay, Jamaica provides a gradient in water turbulence ranging from low (inner back reef) to high (reef crest) to low (deep fore reef) (Boss and Liddell, 1987b). The taphofacies model proposed by Liddell and Martin (1989) for the fringing reef and associated environments at Discovery Bay, Jamaica is defined by the predicted degree of abrasion, dissolution, transport and bioerosion of foraminiferal tests along taphonomic gradients. For example, shallow (5-15 m) fore reef sites exhibit high levels of turbulence, and coarse, well-sorted sediments with low organic content. Liddell and Martin (1989) suggest that foraminiferal tests should exhibit taphonomic signatures indicative of high rates of abrasion. In contrast, back reef (0 - 10 m), fore reef slope (30 - 65 m), deep fore reef (65 - 120 m), and island slope (>120 m) display low turbulence, and usually fine-grained sediments with high organic content. Tests from these sediments are predicted to indicate pronounced dissolution and lower rates of abrasive test reduction. Experimental results from the abrasion and dissolution experiments of this study indicate high preservation potential of the species examined which tend to negate the hypotheses regarding abrasion and dissolution based on the taphofacies model of Liddell and Martin (1989).

On the other hand, though, the comparison of distributional studies (Martin and Liddell, 1988) of the common foraminifera of Discovery Bay inhabiting the reef physiographic zone and knowledge of the energy and organic content of these zones tend to support the model. For example, *Archaias angulatus* and *Amphistegina gibbosa* are the dominant foraminifera of Discovery Bay, Jamaica, and dominate the back and fore reef zones, respectively (Martin and Liddell, 1988). Both species are also relatively resistant to both abrasion and dissolution and can thus persist in sediment assemblages. The back reef lagoon is a low energy setting. Distributional studies (Martin and Liddell, 1988) show that *Sorites marginalis* and *Planorbulina acervalis* to be relatively common in this environment and rare in others. Both foraminifera were shown in this study to be nonresistant to abrasion. Thus, the back reef lagoon is the ideal setting for tests of these thin, fragile foraminifera, if they are to persist in fossil assemblages.

Relevance of Laboratory Studies to Investigation of Fossil Assemblages

The results of this investigation indicate that laboratory experiments on the abrasion and dissolution of foraminiferal tests can yield meaningful results for the interpretation of these taphonomic processes under natural conditions.

The experimental methods designed to simulate the fringing reef environment at Discovery Bay, Jamaica (agitation on the shaker table and dissolution in the seawater table) all gave results which were in close agreement with observations on natural material collected from Discovery Bay. These experiments indicate that it is possible to quantify the extent of taphonomic loss based on surface features detectable on the foraminiferal tests.

The processes of abrasion and dissolution all proceed at highest rates at or near the sediment-water interface, with dissolution being the most effective (Davies *et al.*, 1989). Abrasion rates are typically lower than rates of dissolution. Dissolution is a pervasive process that happens very quickly over geologic time. After only moderate amounts of dissolution, many surface features are destroyed. Abrasion, however, does not destroy surface features as rapidly or as completely (Peebles and Lewis, 1989). Consequently, as an individual agent, dissolution is responsible for most taphonomic loss. Peebles and Lewis (1989) agree that even small amounts of dissolution can affect the integrity of the test by removing surface layers and by weakening the test structure. But it is the interplay of taphonomic processes that causes the most destruction. Most damage occurred to the specimens when the effects of abrasion and dissolution were combined than when either process was the solitary means of destruction. Dissolution will weaken tests, making them more susceptible to abrasion. Based on our calculations, abrasion features may also be useful in determining relative transport distance and sediment residence time (cf.Speyer and Brett,1986).

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