BROWARD COUNTY BEACH DEMONSTRATION PROJECT: FROM BEERS TO BEACHES

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Abstract: Broward County relies on its beaches to attract tourists but 21 of the 24 miles of Broward beaches are defined as critically eroded. The Broward County Office of Waste and Recycling Services processed approximately 15,000 tons of glass each year and is searching for beneficial use of this material. The Broward County Beach Demonstration Project is investigating the feasibility of using recycled glass to augment the shore protection program needs, specifically in areas of higher relative erosion (hotspots). The addition of glass cullet as emergency beach fill may extend the life of the shore protection project by nourishing these areas with smaller volumes of fill. This paper details investigations performed to date including a literature review, geotechnical investigation, biological analyses, public perception research, and abiotic testing and shows that glass cullet is a viable beach compatible material.

INTRODUCTION

Broward County has conducted numerous beach nourishment programs since the early 1960's because its beaches are in a chronic state of erosion. Significantly, 21 of the 24 miles of Broward beaches are defined as critically eroded (Florida Department of Environmental Protection, 2000). Broward County has several potential sources of beach compatible sand including offshore inter-reef sedimentary infills, upland dune, inland sources, and aragonite sand from the Bahama Banks to provide fill for these projects. However, the Broward County Office of Waste and Recycling Services processed 15,840 tons of glass in 2004 at cost of $145,000 (Austin, 2004) and is searching for a beneficial use of this material. Broward County is implementing a demonstration project to determine the feasibility of using recycled glass as beach-compatible material. This material could supply, on an emergency basis, some of the volumetric needs of the County's shore protection program while providing another market for recycled glass.

It is proposed to use glass cullet as a potential alternative source material for beach fill. Glass cullet has physical properties similar to natural silica sands, making it a viable alternative beach fill material along critically eroded shorelines (Finkl and Kerwin,

1997; Kerwin, 1997). Recycled glass cullet has many advantages as a potential alternative beach fill material including:

1. The ability to mechanically select grain sizes comparable to the native beach characteristics;
2. Chemical, mechanical, geologic, and engineering properties of appropriately sized glass cullet are similar to natural sand;
3. The ability to utilize a readily available recycled product;
4. Proactive implementation of a comprehensive recycling program;
5. Utilization of an environmentally safe, inert material.

Despite the potential advantages of glass cullet, additional investigations were necessary prior to placing this material on the beach. The Broward County Beach Demonstration Project has completed a literature review (Thomson *et al.*, 2004a), geotechnical investigation (Thomson *et al.*, 2004b), public perception research (MARS Research, 2004), biological analyses (Makowski *et al*., 2005), and abiotic testing (Makowski *et al*., 2006). This paper outlines the findings from these investigations.

LITERATURE REVIEW

Due to the limited secondary materials market and increasing cost of recycling glass, the Broward County Commission, Office of Waste and Recycling Services conducted a pre-feasibility study on using recycled glass as beach fill material (Malcolm Pirnie, 2003). This study concluded that using glass cullet as beach fill material was a viable concept and recommended that further studies be conducted. A feasibility study for Moonlight Beach, California, conducted by Woodward-Clyde (1993), also showed that glass cullet was a viable beach compatible material.

Studies conducted at Texas A&M University compared the performance characteristics of recycled glass to natural sand (Edge, 2002) in physical model experiments where a 3-D wave tank generated regular waves. The tank was divided into two channels: one for a glass beach and the other for native beach sand. Six tests measured beach profile change due to wave action in the tank. At the end of the test, glass cullet and native beach sands were found to have the same performance characteristics for the conditions tested. The wave reflection coefficient for glass cullet was less than native beach sand, suggesting that glass cullet absorbs energy better than sand.

Also investigated was the rate of abrasion and loss of mass through abrasion (Edge, 2002). A tumbler machine was used to simulate wave action, current, and wind. This experiment measured mass loss for two samples: one was glass only and the other was a mixture of glass plus sand. The latter combination was an attempt to simulate real world effects where the glass cullet and sand are mixed. The glass and sand/glass samples were placed in the tumbler machine with water. After several days of tumbling, the samples were sieved and dried. Grain sizes less than sieve #200 were removed from the sample. Masses were measured after 7, 14, and 36 days of tumbling. These tests showed that the glass-only sample had a very high initial rate of abrasion, but the rate eventually stabilized and was comparable to the glass/sand mixture.

Glass cullet has been placed on two beaches on the Caribbean island of Curaçao, at the Hilton Hotel on Piscadera Bay (southern coast near downtown Willemstad) and at Zanzibar Park (also on the southern coast). Grain sizes of the cullet placed on these beaches ranged from 0.20 mm to 0.60 mm (Paardekooper, 2004).

The volume of glass cullet placed at the Hilton Hotel is unknown, but approximately 110 cubic yards of glass cullet was mixed with native beach sand in a 1,000 square foot area at Zanzibar Park (Paardekooper, 2004) along with a control section of 100% cullet. According to Paardekooper (2004), beachgoers preferred the beach sand - glass cullet mixture compared to the control plot with only glass cullet. This study noted, however, that visitors did not distinguish between sections of the beach that had varying ratios of natural sand to glass cullet. Turtle nesting occurred at both sites but there is no official data available from the local government agency regarding nesting or hatching success (Paardekooper, 2004).

A glass cullet beach was also constructed in the Town of Lake Hood, New Zealand. The Town created a beach using recycled glass cullet to encourage recycling and to increase environmental awareness (Temple, 2004). The lake is man-made, and WasteBusters Trust Canterbury constructed a beach for a festival in January 2003. The "Crystal Beach," composed entirely of glass cullet, is reported to look and feel like natural sand (WasteBusters, 2004).

Literature on two other "glass beaches" was also found. The one in Fort Bragg, California was the site of an old dumpsite. This practice was halted and large items such as cars and refrigerators were removed. Eventually, wave action washed out many of the paper products leaving glass that has become rounded over time. Near the Town of Port Allen on the island of Kauai, Hawaii, there is a beach composed of winnowed glass fragments. The site was a former dumping ground for glass bottles. Reworked by wave action, the glass has been comminuted and reduced to pebble size. However, neither of these beaches is representative of the type of material that is proposed for use on Broward County's beaches.

GEOTECHNICAL INVESTIGATIONS

Geotechnical investigations were conducted to determine grain-size distribution, Munsell color, carbonate content, grain angularity, and chemical analyses for potential contaminants in beach sand and glass cullet. Six samples of beach sand were collected from a back dune area at the southern end of the broad walk on Hollywood Beach, City of Hollywood Beach, Broward County, Florida (following the Broward County Segment III Shore Protection Project). Beach samples, collected as part of the Broward County Shore Protection Project General Reevaluation Report (Coastal Planning & Engineering / Olsen Associates Joint Venture, 2003) were also included in the comparison. Samples of glass cullet were obtained from three manufacturers including: Andela Products Ltd., Richfield Springs, NY; Glass Aggregate Systems, Faribault, MN; Recycle America Alliance, New Haven, CT.

The manufacturers were requested to provide pulverized glass samples that were similar to the grain size distribution of the natural sand along the Hollywood, Florida beaches. The results of the grain size analysis are summarized in the Table 1 below.

Table 1. Summary of Grain Size Analyses.

Sample	Mean Grain Size (mm)	Sorting	Percent Fines [2]
Beach Samples			
Sample #1 (surface)	0.50	0.74	1.7
Sample #2 (-1.5 ft)	0.47	0.76	1.1
Sample #3 (-3ft)	0.46	0.86	0.7
Sample #4 (surface)	0.54	0.77	1.6
Sample #5 (-1.5ft)	0.48	0.67	1.1
Sample #6 (-3ft)	0.51	0.82	0.7
Average	0.49	0.77	1.2
GRR Beach Samples [1]			
R-114 (dune)	0.65	0.97	0.0
R-114 (mid berm)	0.44	0.82	0.4
R-117 (dune)	0.38	0.61	0.3
R-117 (mid berm)	0.43	0.50	0.1
R-117 (mean high water)	0.71	0.58	0.0
R-117 (mean tide level)	0.83	0.64	0.0
Glass Cullet Samples			
Andela Products	0.89	1.12	3.7
Glass Aggregate Systems	0.40	0.84	2.7
Recycle America Alliance	0.33	0.95	7.5

1. CPE/Olsen J-V, 2003
2. Percent material passing the #230 sieve.

Table 1 shows that there was a range of mean grain sizes produced by the glass cullet manufacturers that bracketed the grain size values observed for the beach samples. Equally important is that the percent fines was low. The Florida Department of Environmental Protection (FDEP) requires that beach fill sediments contain no more than 5% fines (silt plus clay).

Public perception and FDEP requirements require that glass cullet looks like beach sand. A Munsell Color analysis was performed and the results are summarized in Table 2.

Table 2. Summary of Munsell Color Analysis.

Sample	Munsell Color Value		Munsell Color Description	
	Dry	Wet	Dry	Wet
Beach Samples				
Sample #1 (surface)	10YR 7/1	10YR 6/2	Light gray	Light brownish

				gray
Sample #2 (1.5 ft)	10YR 7/2	10YR 6/3	Light gray	Pale brown
Sample #3 (3ft)	10YR 7/2	10YR 6/3	Light gray	Pale brown
Sample #4 (surface)	10YR 7/1	10YR 6/2	Light gray	Light brownish gray
Sample #5 (1.5ft)	10YR 7/2	10YR 6/2	Light gray	Light brownish gray
Sample #6 (3ft)	10YR 7/2	10YR 6/3	Light gray	Pale brown
Glass Cullet Samples				
Andela Products	5Y 3/2	5Y 5/2	Olive gray	Dark olive gray
Glass Aggregate Systems	2.5Y 8/3	5Y 6/4	Pale yellow	Pale olive
Recycle America Alliance	10Y 8/1	5Y 6/3	Light greenish gray	Pale olive

Beach sands can be broadly categorized by their chemical composition into either carbonate beaches ($CaCO_3$) or siliciclastic/quartz (SiO_2) beaches. The beaches in Broward County are a mixture of bioclastic carbonate sands (coquina shell fragments, reef fragments, and skeletal fragments of marine organisms) and silica sands in the form of quartz (Coastal Planning & Engineering / Olsen Associates Joint Venture, 2003). The carbonate content is important because carbonate sands perform differently than silica sands due to different intraparticle porosities, density, bulk density, and structural integrity of carbonate grains (Halley, 2000). In Miami-Dade County, weathering of carbonate sands produces sediments with higher concentrations of silt and clay sized material, which results in elevated turbidity levels in the nearshore zone (USFWS, 2002). Glass cullet avoids these issues because it is composed primarily of silica-based compounds and fines can be controlled prior to placement on the beach.

The average carbonate content of the beach samples was 70%, but ranged from 61% to 84%. The glass cullet samples were not tested for carbonate content because they are chemically 100% silica.

The angularity, or roundness, of individual grains affects sediment settling and motion initiation. It can also be important as a public perception issue. Sample grains of the beach sand and glass cullet were placed under a microscope and visually examined to determine grain angularity using Power's visual classification (Powers, 1953). The existing beach sand is rounded to sub-angular with both high and low sphericity values while the glass cullet was very angular with low sphericity. Edge (2002) showed that glass cullet abrades but that the rate of abrasion decreases and stabilizes with time. Therefore, the angularity of the glass cullet can be expected to decrease over time. Angularity is not expected to have a significant impact on the performance of the glass cullet as beach fill.

FDEP requires that for fill material to be considered beach-compatible that it must not contain toxic material, as specified in Section 62B-41.007 (2)(j)(4) of the Florida Administrative Code. Glass cullet and beach sands were tested for contaminants as part

of the geotechnical investigations. Beach sands were used as a control or guide to general background contaminant levels to which the glass cullet would be compared. Tests were performed to detect the presence of lead (Pb), mercury (Hg), total coliform, fecal coliform, enterococci bacteria, 85 semi volatile organics (8270C test), petroleum hydrocarbons (FL-PRO test), and total salt content. Only 5 of the semi-volatile organics registered and these were all below the FDEP (2001) level for direct residential exposure.

PUBLIC PERCEPTION

A public perception investigation was performed by MARS Research (2004) to determine whether the concept of using glass cullet would be accepted by the public. The analysis was broken into three parts: a focus group meeting with beach professionals; a focus group meeting with tourism representatives; and a random phone survey of over 400 Broward County representatives.

The beach professionals were most skeptical about the concept. Most of their concerns did not appear to be with the concept of using recycled glass but of the likelihood that it could be permitted. Interestingly, once the beach professionals were shown a sample of the glass cullet, they adopted a more positive attitude. The beach professionals had several questions regarding the performance of the glass cullet that could not be answered at the time, as most of the investigations presented in this report had not been performed yet. These questions included the similarity of glass cullet to natural beach sand with respect to abiotic and environmental factors.

Overall, the tourism professional focus group was supportive of the concept. Their primary concern was erosion of the beaches, which is obviously one of the key reasons that tourist visit Broward County.

The phone surveys showed that there was support from the public with 89% approving of the concept (45% completely approved, 35% somewhat approved, while 9% disapproved). Overall, the findings were that using glass cullet for beach nourishment is appealing, interesting, and relevant to the public.

BIOLOGICAL ANALYSES

In response to a directive from the Florida Fish and Wildlife Conservation Commission (FFWCC) and FDEP, the CPE team developed a phased scientific investigative program to evaluate material effects on invertebrate and vertebrate (fish) biotic community assemblage. Other studies have demonstrated that experimental bioassays can accurately detect either adverse or benign effects on marine organisms (Peters *et al.*, 2002; Ringwood and Keppler, 2002). In addition, State resource protection agency representatives have suggested that the habitation and colonization of lower invertebrates may serve as a good indicator of the effect recycled glass cullet will have on higher vertebrates. These investigations were undertaken to validate the hypothesis that recycled glass cullet is a viable beach fill alternative to more traditional sand

sources. A complete record of this study and the data found are presented in Makowski & Rusenko (in press).

The objective of the biological investigation was to monitor the colonization and survivability of lower invertebrates and fish, through experimental bioassays, in various cullet mixtures. A saltwater flow system was utilized to simulate natural beach conditions within each test matrix. Direct observations and supplemental chemical analyses were conducted to determine whether recycled glass cullet has an affect on biological communities.

Five combinations of glass cullet and beach sand were investigated: 100% beach sand, 75% beach sand/25% glass cullet, 50% beach sand/50% glass cullet, 25% beach sand/ 75% glass cullet, and 100% glass cullet. Saltwater, obtained through the Gumbo Limbo Nature Center oceanic intake system, was delivered through a network of PVC pipes to each test container and provided a constant supply of fresh saltwater (approximately nine water changes over a 24 hr period) to the marine organisms and sediments. Each combination of sand/cullet had three replicate containers. Photo 1 shows three of the containers used to perform the bioassays.

Species introduced into each test matrix were collected or supplied by the Gumbo Limbo Nature Center of Boca Raton, Florida, and included local representative microfauna (i.e., copepods, ostracods, nematodes) and macrofauna organisms (i.e., crustaceans, mollusks, fish). All testing and recorded observations were conducted from May to July, 2005, at the Gumbo Limbo Nature Center.

Macrofaunal organisms were allowed a 24-hour acclimation period before monitoring was initiated. Live marine shrimp were added weekly as a source of food, and uneaten material was not allowed to accumulate in the containers. Biological monitoring of macrofaunal test organisms were conducted through direct visual observations performed at least twice per week for the duration of the study. Macrofauna success rate was calculated by taking the proportion of survived individuals over the total number of individuals introduced to a specific sediment matrix. A complete census of all individuals was taken on a weekly basis.

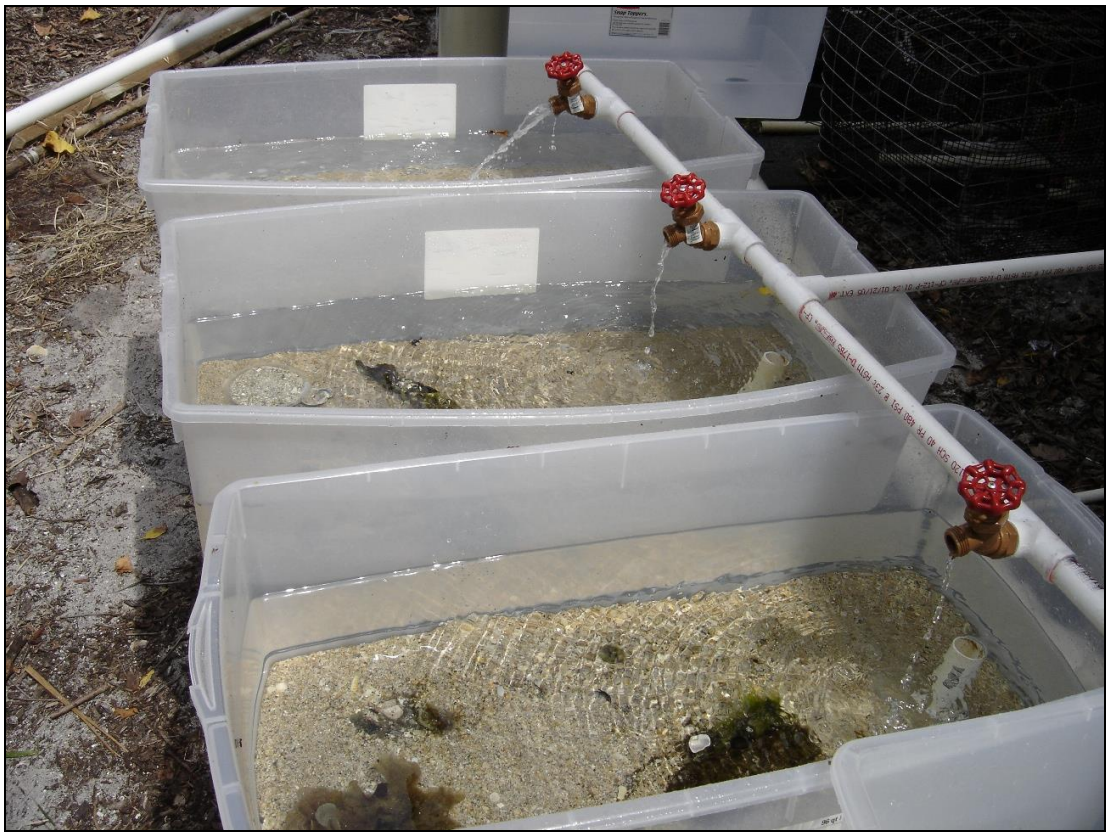

Photo 1. View of the containers used to perform the bioassays.

Microfauna organisms were introduced to each test container by taking a five pound sample of 'live' sand from established (nitrogen cycled) reef display tanks located at the Gumbo Limbo Nature Center. A one-week acclimation and colonization period was allowed before monitoring was initiated.

Biological monitoring of microfauna test organisms was conducted through interstitial core analysis. A 50.1 g interstitial core sample was extracted from each test matrix using a 0.5m long piece of ½ inch PVC pipe and a stopcock. Core samples were taken on a weekly basis and analyzed for the presence/absence of microfauna under a trinocular video microscopy system at a total magnification of 400x. Identification of microorganisms was through external characterization, and active status of individuals was digitally documented.

An important and unexpected observation during the study was the formation of a blackish film that began to develop on the different cullet sediment mixtures after three weeks of testing, first starting on the 100% cullet and then appearing on all the other experimental series, including the controls near the end of the testing period. Further analysis determined that the black film was a precipitation of hydrogen sulfide. This anaerobic sulfide-reducing process has been documented in stagnant coastal waterway systems that lack influential wave action (Carlson *et al.*, 1994). However, when

sediments containing the cullet were mixed and allowed to aerate by directing water movement into the substrate (wave simulation), the visible hydrogen sulfide accumulations disappeared, and no microbial zonation was detected. Hydrogen sulfide test readings also showed that levels were decreased after the wave simulation and aeration was initiated.

After a two-month exposure to glass cullet sediments, it was determined that the artificial cullet substrate did not adversely affect macro-organism habitation or micro-organism colonization. This was evident with the uniform lack of mortality observed in the introduced individuals and the active presence of interstitial microfauna.

Individuals displayed normal active behavior within the cullet matrices and showed no adverse signs of physical stress. Of particular note, was the use of the cullet as defensive camouflage by the test crustaceans and mollusks. In order to shield themselves from predators or direct UV light, the sargassum and blue crabs would thrust their carapaces backward into the cullet until they were completely covered. This behavior was shown repeatedly over the testing period with no harm to the crabs. Similarly, whelks would burrow deep into the cullet as a protective measure, and would do so with no observed injury to their foot or mantle.

Microscopic analyses revealed that colonization of interstitial microorganisms were successful within the cullet mixtures. All the same classes of microorganisms were observed in the control as well as the experimental replicates. Interstitial movements were documented and showed that microorganisms were able to actively transport without adverse effects. Uniform colonization of the sediment mixtures was also reaffirmed by the consistent organic content readings in all the test series.

ABIOTIC ANALYSES

Supplemental testing of abiotic factors was deemed necessary by the FFWCC and FDEP to document the acceptability of glass cullet as an alternative beach fill material. The abiotic factors of temperature, humidity, and gas exchange are considered the most important abiotic variables affecting the survival of reptilian embryos (Ackerman, 1980, 1991; Miller, 1985; Packard and Packard, 1988; Maloney *et al.*, 1990; Mortimer, 1990). In this case, sea turtles were identified as the species of concern. Florida serves as one of the most important nesting environments for sea turtles in the United States, with more than 50,000 nests annually. When an alternative sediment type is introduced to the system, the main concern is that a foreign incubation environment may be produced. Sand acts as a barrier through which water vapor, carbon dioxide (CO_2), and oxygen (O_2) diffuse and dissipate heat. For incubation to be successful and produce hatchlings onto the beach surface, the nest environment must facilitate embryonic development (Georges *et al.*, 1993). Minute differences in temperature, moisture, and gas exchange have the potential of dramatically affecting the sex ratios and survivability of sea turtles during their developmental stages (Mrosovsky and Yntema, 1980; Standora and Spotila, 1985; Mrosovsky, 1988).

The purpose of this *in situ* study was to determine if glass cullet mixtures exhibit the same abiotic characteristics (temperature, moisture content, and respiratory gas exchange) when compared to the current beach sediments. Within the glass cullet, the synergism between moisture, temperature, and gas exchange must be similar to natural beach conditions in order to avoid impacts to the development of embryos during incubation. A complete record of this study and the data found are presented in Makowski *et al.* (in review).

A test plot was constructed on a beach in the City of Hollywood Beach, Broward County, Florida in March 2006. The test plot was 12 m (40 feet) long, 3 m (10 feet) wide, and 1 m (3 feet) deep. Sixteen individual test sections (4 sections for each of the 4 natural beach/glass cullet mixtures) were constructed within the test plot. Each section was 1.5 m (5 feet) by 1.5 m square and 1 m (3 feet) deep. The four natural beach/glass cullet mixtures tested were 100% beach sand, 75% beach sand/25% glass cullet, 50% beach sand/50% glass cullet, and 25% beach sand/75% glass cullet. Photo 2 shows the test plot with each individual section roped and labeled.

Photo 2. A view of the test plot with the rope demarking varying mixture sections.

Using three programmed data loggers placed in each of 16 simulated nests within the native sand/glass cullet matrix, measurements are obtained at the bottom, center, and near the top of each monitoring section. The data loggers collected specific

measurements on temperature and relative humidity every half hour. In addition to the temperature and humidity measurements, gas probe samples are analyzed weekly for O_2 partial pressures (gas exchange) using an oxygen gas analyzer.

After a 171 day testing period (March to August 2006), it was determined that all glass cullet test sections offered a suitable nesting environment for incubating sea turtle embryos based on the measured abiotic factors . Temperature in the glass cullet sections was found to be insignificantly different from the native beach sand controls. All sections, experimental glass cullet and control, logged similar dew point temperatures and relative humidity readings that would allow sea turtle eggs the necessary moisture during incubation. And gas probe samples taken from all the experimental cullet test section recorded high concentrations of oxygen, with no significant variations from the beach sand controls.

UPCOMING WORK

The next step of the project is to place glass cullet along the beach and determine how it performs. A proposal to place and monitor approximately 765 m^3 (1,000 cubic yards) along the beach in The City of Hollywood, Broward County is currently being reviewed by Regulatory Agencies.

CONCLUSION

The analyses conducted to date show that glass cullet is a viable, beach compatible, fill material. The geotechnical analyses suggest that the grain size, color, percent fines, and angularity of glass cullet are sufficient to characterize the material as beach compatible. Contaminant analyses show that the material is clean. The public perception research suggested that the public is amenable to the concept of using glass cullet as a source of beach fill. Biological and abiotic testing both suggest that there will be no impact to microfauna or macrofauna communities, and that sea turtle embryo development will not be impacted due to the use of this material upon the beach.

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