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THE USE OF ARAGONITE AS AN ALTERNATE SOURCE OF BEACH FILL IN SOUTHEAST FLORIDA

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ABSTRACT: The first full-scale use in the United States of imported aragonite sand for beach restoration was initiated at Fisher Island, Florida, in December, 1990. The project involved placement of 35,500 cy of aragonite fill stabilized by seven rock structures. The structure plan makes use of classic headland and spiral-bay shoreline behaviour to induce a net desired littoral drift pattern. This pattern and the predicted equilibrium fill planform was selected to minimize fill losses and to minimize impacts to nearshore sea grass beds.

INTRODUCTION

Oolitic aragonite commercially mined in the Bahamas has been proposed as a candidate source of compatible beach fill for the State of Florida since the early 1960's. Aragonite is composed of calcium carbonate crystallized in smooth spherical or ellipsoidal shapes. To date, however, the material has never been deemed sufficiently cost effective in comparison to locally dredged offshore sands to justify its actual application. Increased dredging costs, environmental impacts and the general scarcity of suitable nearshore sand deposits at some locations, however, have helped to maintain aragonite as an attractive alternate.

In December, 1990, construction began on the first full-scale beach nourishment project to utilize oolitic aragonite in the United States. The project is located along the Atlantic shoreline of Fisher Island, Dade County, Florida (Figure 1). The island was created in about 1904 when the southerly tip of the original undeveloped coastal barrier which today comprises Miami Beach was severed to form Government Cut. Subsequent to the excavation and

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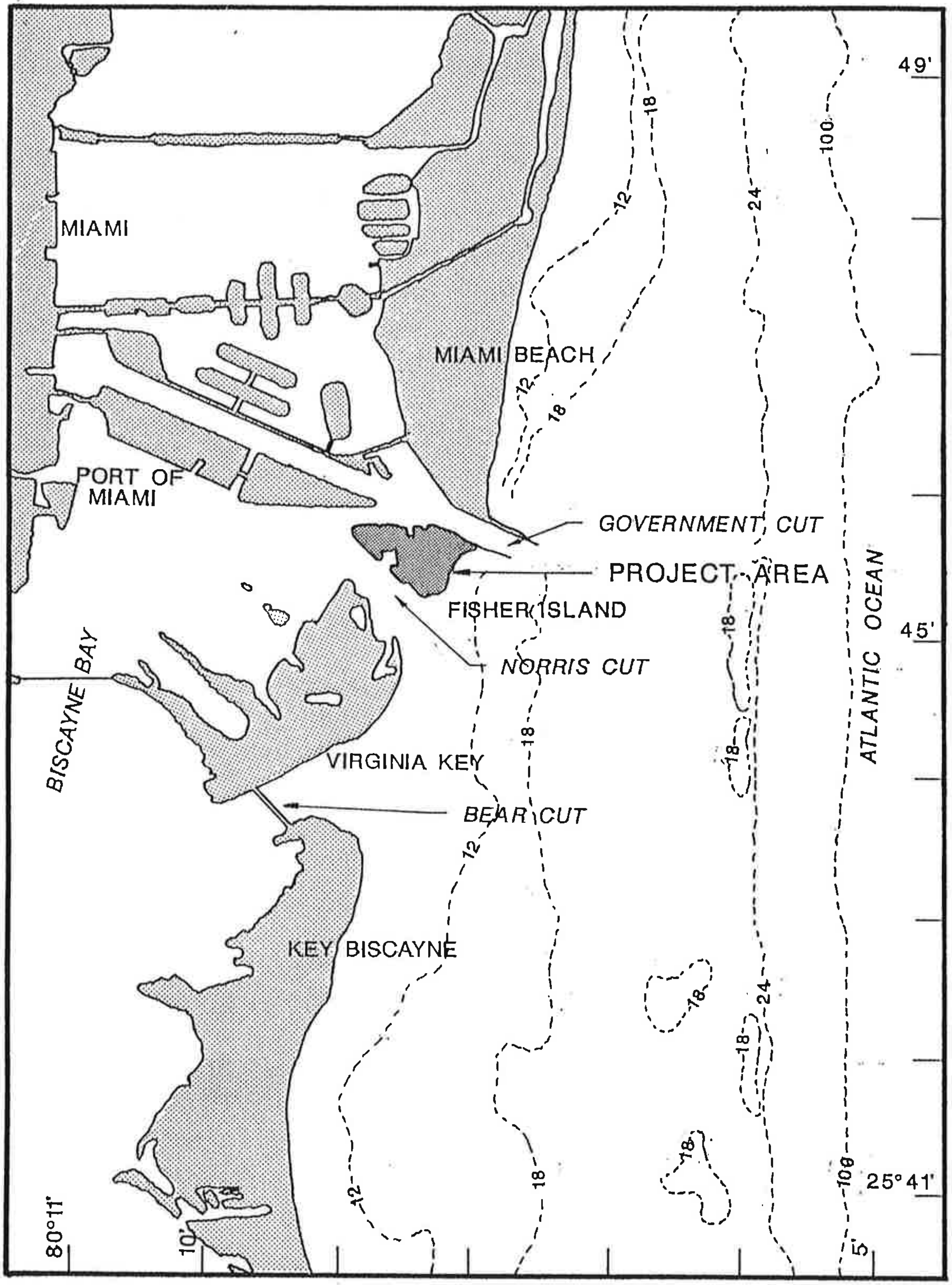

Figure 1: Location map of project area; Dade County, Florida.

construction of jetties associated with the navigation project, the island's Atlantic shoreline has retreated an average of 338 ft, or about 4 ft/year since 1904.

Fisher Island is a private residential and resort development consisting predominately of multi-family dwellings. The local scarcity and environmental sensitivity of upland and offshore sand sources, the developer's interest in creating a unique and attractive beachfront, and the relatively modest size of the beach fill requirement made imported Bahamian aragonite an excellent candidate for beach nourishment material at the site.

As a result of the adjacent navigation project, the site can be considered to comprise an independent littoral cell from which sand is readily lost but not recovered. The site also includes environmentally sensitive nearshore seagrass beds. These factors required that the placed fill be stabilized in order to minimize losses and to limit encroachment upon the seagrass. To accomplish this, an innovative use of stabilizing structures, modeled after Mediterranean and Eastern European type designs, was employed in the project. Hence, the Fisher Island project is a novel opportunity to study -- in prototype scale -- the performance of both aragonite beach fill and a highly tuned field of coastal structures.

PROPERTIES OF OOLITIC ARAGONITE

Background. Oolitic aragonite is composed of calcium carbonate crystallized in the orthorhombic crystal system which occurs in the form of smooth spherical or ellipsoidal shapes (Cunningham, 1966). A nucleus (or "seed") is usually present within each aragonite crystalline growth composed of quartz, Foraminiferal tests, or other carbonate particles (Kuenen, 1933; Robinson, 1967).

Most beaches in southeastern Florida are composed of quartz sand and carbonate shell although beaches near and south of Biscayne Bay are composed primarily of calcitic carbonate sand. Carbonate beaches which are dominated by aragonite do not occur in Florida, but aragonite is a common component of many sub-tropical Florida beaches (Thorp, 1939). The substrata of southeastern Florida beaches feature oolitic rock (Wanless, 1969). The beaches and seabeds of the Bahamas, on the other hand, are composed primarily of aragonite.

The origin of oolitic sand is not certain. An organic theory suggests that aragonite precipitates from seawater due to an increase in pH caused by biological activity (Kuenen, 1933). The inorganic theory suggests that the precipitation is due to colder oceanic waters which flow onto the warm, shallow Bahama Banks (Newell et al., 1960). Existing evidence supports both theories (Miller-Way et al., 1987).

Although both aragonite and calcite are calcium carbonate, their different crystalline structures cause differences in their properties. While calcite has a Mos hardness of 2.5 - 3.0 and a specific gravity of 2.71, aragonite has a hardness of 3.5 - 4.0 and specific gravity of 2.95 (Miller-Way et al., 1987).

Equivalent Grain Size Behavior. Settling tube comparisons demonstrate that aragonite behaves as a coarser material than a quartz grain of equivalent size (Campbell, 1983). In fact, re-evaluation of these comparisons, prepared for this paper, suggest that aragonite potentially behaves as sand with an equivalent median grain size which is 1.36 times coarser than that measured by sieve analysis (see Table 1).

Table 1: Summary of Comparative Grain Size Analysis.[1,2]

	--Sieve Analysis---		--Settling Tube--		
Sample Type	Meas'd	Normalized[3]	Meas'd	Normalized[3]	% inc.[4]
Aragonite	0.290	1.000	0.340	1.000	--
Pompano #A-4(2)	0.274	0.945	0.233	0.685	138%
Lake Worth #18	0.268	0.924	0.233	0.685	135%
Ocean Ridge #C-2	0.167	0.576	0.159	0.468	123%
Jupiter #12	0.110	0.379	0.088	0.259	146%
				Average =	136%

1 Measured data are from Campbell, 1983
2 Measured values are in millimeters (mm).
3 Normalized against aragonite values.
4 Example: Pompano samples falls 0.685 times as fast as aragonite but is 0.945 times its size. Hence, aragonite sample falls 0.945/0.685 = 1.38 times faster than expected for its size.

Beach Slope. Data which explicitly relate beach slope to aragonite grain size are unavailable. However, beaches naturally composed of aragonite are common to the Bahamas. Profiles of three Bahama beaches were surveyed for the present study (i.e., at North Cat Cay and North Bimini). The "active" profile slope below MHW and above about -6 ft MTL is about 1:7 (V:H). (The beach fill at Fisher Island extends to a depth above about -5.5 ft MTL). The three surveyed beaches include very coarse, well sorted aragonite with median grain size (d_{50}) in excess of 0.5 mm.

Field data exist which weakly correlate median grain size and fore-shore slope for typical U.S. beaches composed of quartz and feld-spar materials (USACE, 1984). These data suggest that the fore-shore slope of the aragonite beach fill at Fisher Island may be as steep as 1:7.4 or 1:10, respectively assuming a low wave energy environment (akin to Florida Panhandle conditions) or a moderate wave energy environment (akin to New Jersey - North Carolina conditions). These predictions are based upon a sieved median grain size of 0.27 mm for the placed fill -- where it was assumed that the placed fill will behave like a quartz sand which is 1.36 times greater in size, or 0.37 mm.

SUITABILITY OF ARAGONITE FOR BEACH NOURISHMENT

Previous Prototype Studies. Full-scale (prototype) beach restoration using aragonite has not been attempted prior to the Fisher Island project. A small test project, involving 1000 tons (or about 800 cy) placed at about MHW by truck-haul, was executed in 1965-66 at Pepper Park, two miles north of Ft. Pierce Inlet, Florida (Cunningham, 1966). Because of the small quantity of fill material and inadequate controls, the results of this small scale test were inconclusive.

Laboratory Studies. Saltwater wave tank tests conducted by the Coastal Engineering Research Center (Monroe, 1969) concluded that "oolitic aragonite, if used for beach nourishment would react to the waves in a manner similar to normal sand of the same size." These tests did not specifically address potential problems of abrasion; however, no loss of oolite sand due to abrasion was noted in the tests. The oolite sand showed less erosion than similar-size quartz sand at the still water level.

Unpublished results from laboratory tests conducted by the U.S. Army Corps of Engineers (1985) concluded that aragonite sand "appears suitable for beach renourishment material." These tests included abrasion evaluation, wet/dry testing in fresh and sea water, solution testing for acid rain conditions, detail microscopic constituent determination, x-ray diffraction analysis, bulk specific gravity, and absorption.

Because of aragonite's greater settling velocities relative to quartz sands, it may be a physically superior beach fill material over typical sands. All laboratory tests to date conclude that aragonite is potentially suitable for beach restoration in southeast Florida. Nonetheless, concerns remain regarding its potential for abrasion, dissolution, cemetation, and effects to benthic and pelagic assemblages.

Aragonite is known to be less durable than quartz sand (Mos hardness = 7) and is expected to abrade in the presence of quartz. Dean (1989) qualitatively found that the aragonite in a sand/aragonite mixture tumbled in a saltwater bath abraded slightly more rapidly than in a pure aragonite sample. In both cases, however, the aragonite "seasoned" rapidly -- yielding most of the abraded material upon initial tumbling with reduced abrasion losses thereafter. One might conclude, then, that abrasion losses should be minimized for aragonite beach nourishment placed in areas with little native quartz sands, or in areas with predominately native calcite sands (which are less hard than aragonite).

Significant or episodic efflux of freshwater (via seepage, riverine discharge, or rainfall), and/or local undersaturation of calcium carbonate in the water may result in partial dissolution of the aragonite. Alternately, cementation of recent calcarenite (coquina) by aragonite may result in the formation of beach rock (Keunen, 1933). However, because neither beach rock nor cay sandstone are presently forming along the southwest Florida coast north of the Keys (despite the abundant presence of calcite which also cements coquina), formation of beach rock by the introduction of aragonite is not expected. Further, investigations by Bathhurst (1971) suggest that local seawater chemistry, rather than sediment type, is the most important factor in controlling beach rock formation.

Adverse impacts to the benthic community due to the introduction of aragonite to the beach are not expected assuming that the grain size distributions of the existing beach sands and the aragonite fill materials are similar, and because the presence of organics is not anticipated to change after placement of the aragonite (CSA, 1989). The accentuated roundness of the aragonite particles may increase porosity and permeability, but this may be balanced by perceived compaction of the aragonite. Hence, in-place porosity and permeability will likely be similar to existing conditions. Because ooliths form in the marine environment, trace impurities in the crystalline structure are present in aragonite relative to calcite sand. However, no evidence exists to suggest that the mineralogy of carbonate beaches is an important ecological parameter (Miller-Way, et al., 1987).

Limited investigations of the effect of aragonite sand upon sea turtle nesting and hatching include those of Nelson et al.(1987) and Nelson and Fletemeyer (1988). Further study is required before definitive conclusions can be made (Nelson, personal communication). Sea turtle nesting is known to occur on carbonate beaches in Florida Bay (Davis and Whiting, 1977; Roberts et al., 1977) and on aragonite beaches in the Bahamas (as reported by marine wildlife officers, Bahamas).

FISHER ISLAND: SITE CHARACTERISTICS

As noted, Fisher Island was created by the excavation and stabilization of Government Cut inlet between 1904 and 1929. These works severed the island from the net southerly littoral drift along Miami Beach, to the north. The island's atlantic shoreline was originally about 3,000 feet long. However, the island's southern flank eroded between 600 to 850 feet before it was stabilized by revetment and a terminal groin in the early 1980's. Within 250 feet of Government Cut's south jetty, the shoreline is stable due to the jetty's shadow effect and a minor impoundment fillit. South thereof, the remaining 2200 ft of shoreline has retreated between 400 and 485 ft since pre-inlet conditions (Bodge, 1989). An unknown quantity of rock and sand spoiled along the shoreline in the 1940's tempered these observed erosion estimates.

Grid-based wave refraction analysis of the area suggests that the shadow effect of Government Cut and its jetties extends to between 500 ft and 1500 ft south of the south jetty. A strong gradient exists beginning 1500 ft south of the jetty where the net southerly littoral drift potential rapidly accelerates to perhaps 120,000 cy/yr towards the island's southern end (Bodge, 1989). (See Figure 2).

In the early 1980's a 400-ft long terminal groin was constructed at the shoreline's south end (about 2450 ft south of the jetty) and a short groin and culvert was located about 680 ft north thereof. The pre-project recreational beach width was about 20 ft to 46 ft along the southern 250 ft of the shoreline and less than 10 ft along the south-central 850 ft of shoreline. The remainder of the shoreline had eroded to a vertical limerock scarp with no dry beach.

Government Cut effectively precludes sediment from naturally reaching Fisher Island from Miami Beach to the north. Norris Cut and the island's southern terminal groin, in addition to the local net southerly drift, restricts the sediment supply from Virginia Key to the south.

Dominant northerly wave energy erodes at least the southern half of the Fisher Island shoreline. The eroded material is partially impounded against the southern terminal groin and is eventually bypassed to Norris Cut and apparently lost to tidal currents. Southerly wave energy transports existing sand northwards towards the jetties. This material partially impounds against the south jetty or circulates clockwise in the jetty's lee -- returning to the shoreline about 1500 ft south of the jetty. Overall, then, Fisher Island represents a more-or-less isolated littoral cell.

Seagrass beds were identified about 130 ft from the pre-project MHWL along the southern half of the shoreline, and in scattered patches within 50 to 90 ft of the MHWL along the northern half.

PROJECT DESIGN

In an effort to partially restore Fisher Island's eroded atlantic shoreline, a beach restoration project was designed for the southern 2060 feet of shorefront. The design calls for the placement of up to 35,500 cy of commerically mined aragonite barged from Ocean Cay in the Bahamas. The aragonite is delivered in 1600-cy bargeloads where it is conveyed directly to dump trucks which subsequently haul the material to the beach project site for deirect placement. The sediment is delivered with an estimated 6% moisture content.

In this way, the beach fill is imported from an external site and is placed in an approximately dry state. This eliminates potential dredging-related impacts normally associated with nearshore borrowing and minimizes nearshore turbidity at the fill site.

In order to minimize losses and encroachment of the fill upon the seagrass beds, an innovative structural system was designed to stabilize the beach fill. The plan design makes use of the classically known behavior of a sandy shoreline perched between fixed

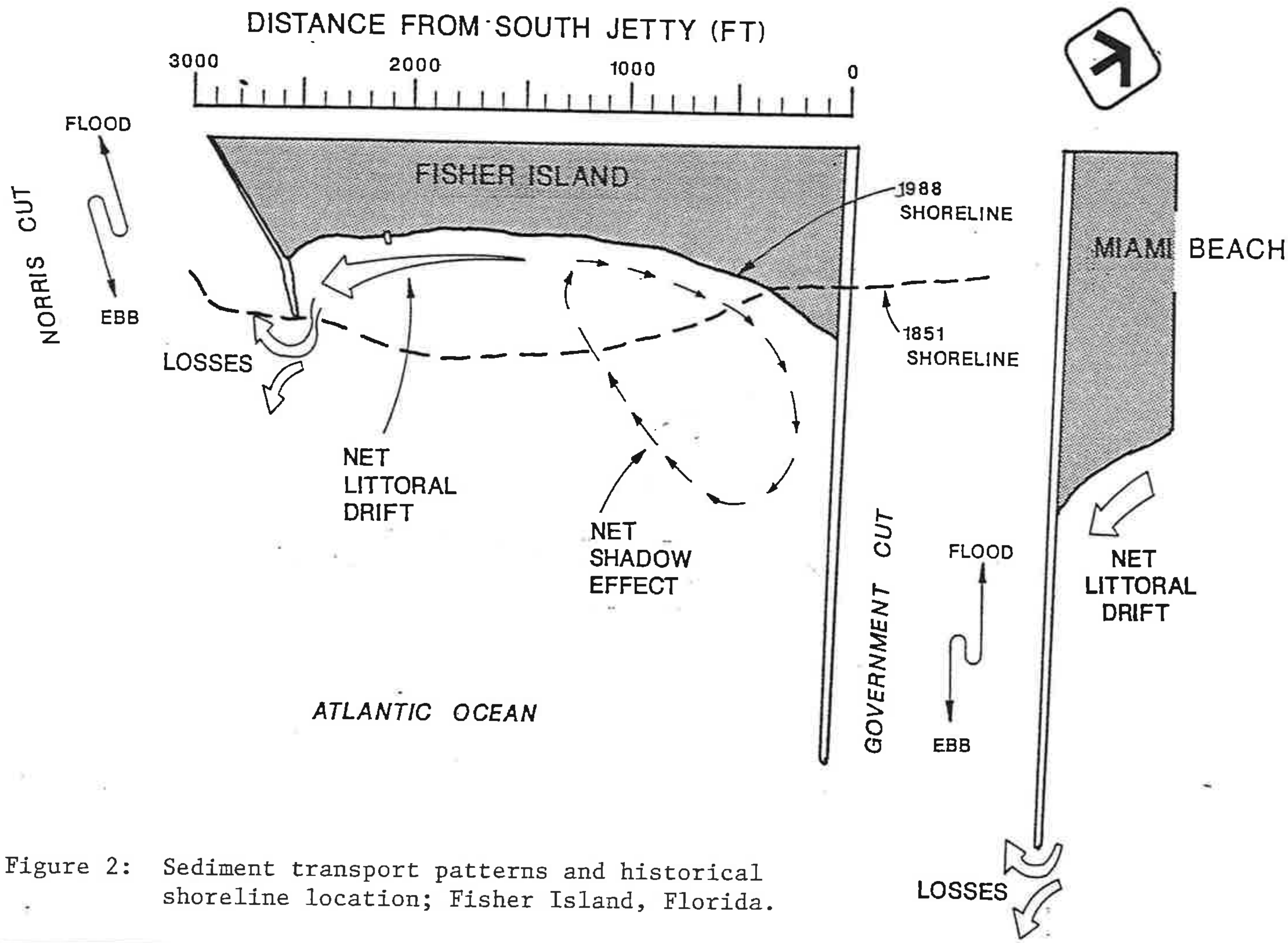

Figure 2: Sediment transport patterns and historical shoreline location; Fisher Island, Florida.

headlands (see, for example, Yasso, 1965; Silvester, 1970; Silvester and Ho, 1972). In the case of Fisher Island, the aragonite beach fill acts as the sandy shoreline, and the rock structures act similarly to the headlands. The orientation of the structures (particularly their seaward heads) is designed in accordance with the local wave direction so as to impose a littoral drift pattern which yields optimum project performance.

The plan's rationale is presented herein. Assume, as is shown in Figure 3, that waves of an average, constant direction approach a sandy pocket between two headlands. The orientation of the headlands varies between the three cases shown in the figure. In Figure 3a, the shoreline is "straight" such that the waves make an angle to the sandy pocket and net drift to the left results. If the headlands are shifted so as to align perfectly with the incident waves (Figure 3b), no net drift results. If the headlands are shifted further (Figure 3c), a drift "reversal" is imposed and net drift to the right results. Hence it is seen that the response of the shoreline is controlled by the positioning of the headlands relative to the incident wave direction.

Figure 4 illustrates the use of structures to impose a desired shoreline orientation and drift direction along a section of a beach fill. In the example, the average wave direction is taken as perpendicular to the local, pre-project shoreline. The orientation of the two structures' heads is then selected relative to the wave direction in order to impose the desired shoreline angle and drift direction.

Figure 5 describes the average local wave direction and desired shoreline response along the Fisher Island project area. The local wave direction at each beach-fill compartment was determined from inspection of the existing shoreline -- and was substantiated by wave refraction analysis. The configuration of the stabilizing structures was "tuned" for the following response: A net southerly drift is imposed along the north end of the project area (in the shadow of the Government Cut jetties) which reduces to zero net drift towards the project's center. A slight northerly drift reversal is imposed along the southern terminus of the project area. The classical log-spiral shoreline orientation between the structures' heads -- combined with the size and positioning of the heads themselves -- is also intended to minimize slumping of the beach fill near environmentally sensitive areas identified by the consultant and regulatory agencies. The northern structures feature long heads designed to isolate seagrass patches from the fill. These heads are connected to the upland to prevent flanking failure and fill "wash-out" during severe storms.

The appearance of the beach and structural plan is similar to artificial beach projects in the Mediterranean. Similar "tuned" structures are also described for beaches in Eastern Euopre (Spataru, 1990).

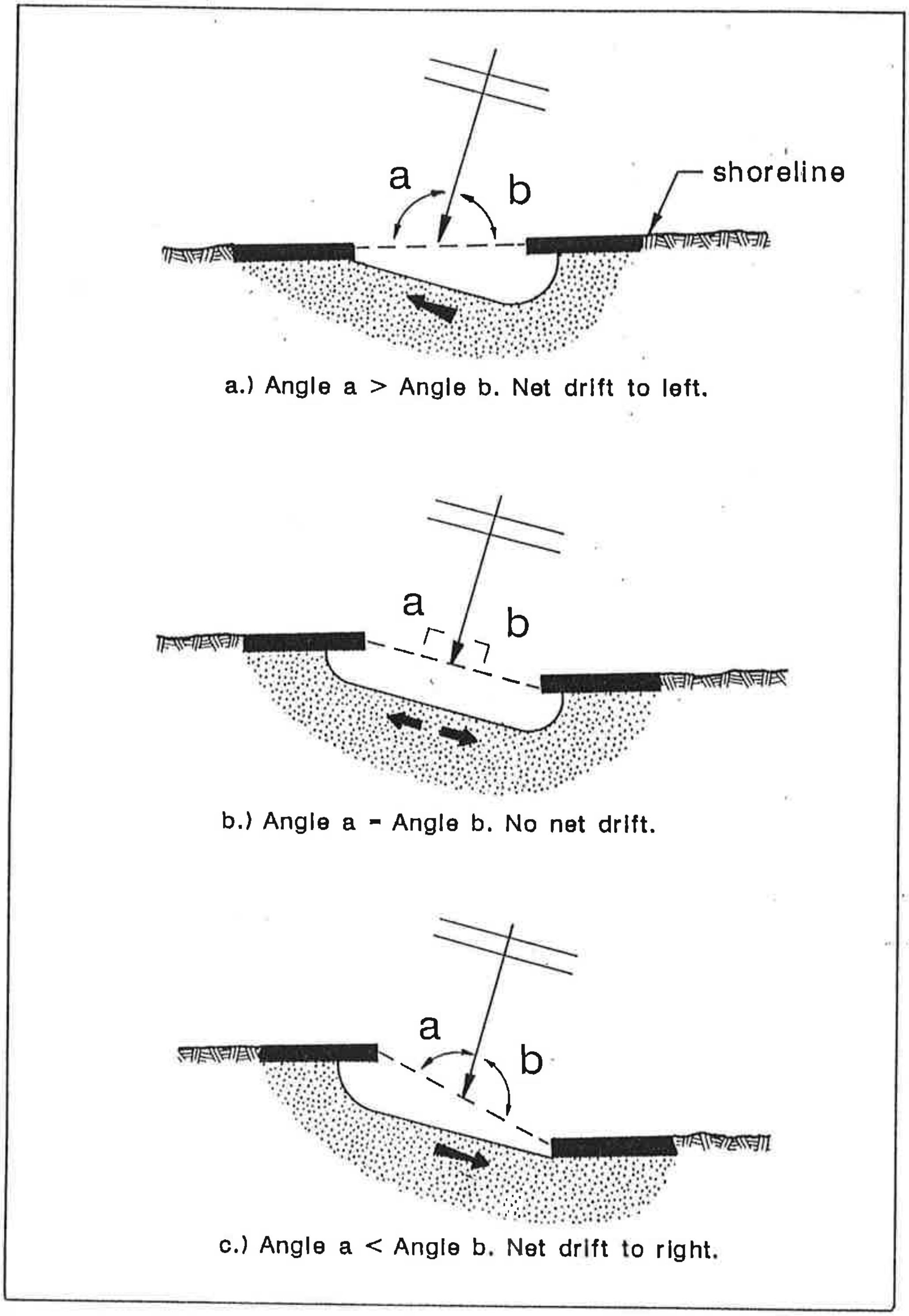

Figure 3: Effect of headland orientation on net drift direction.

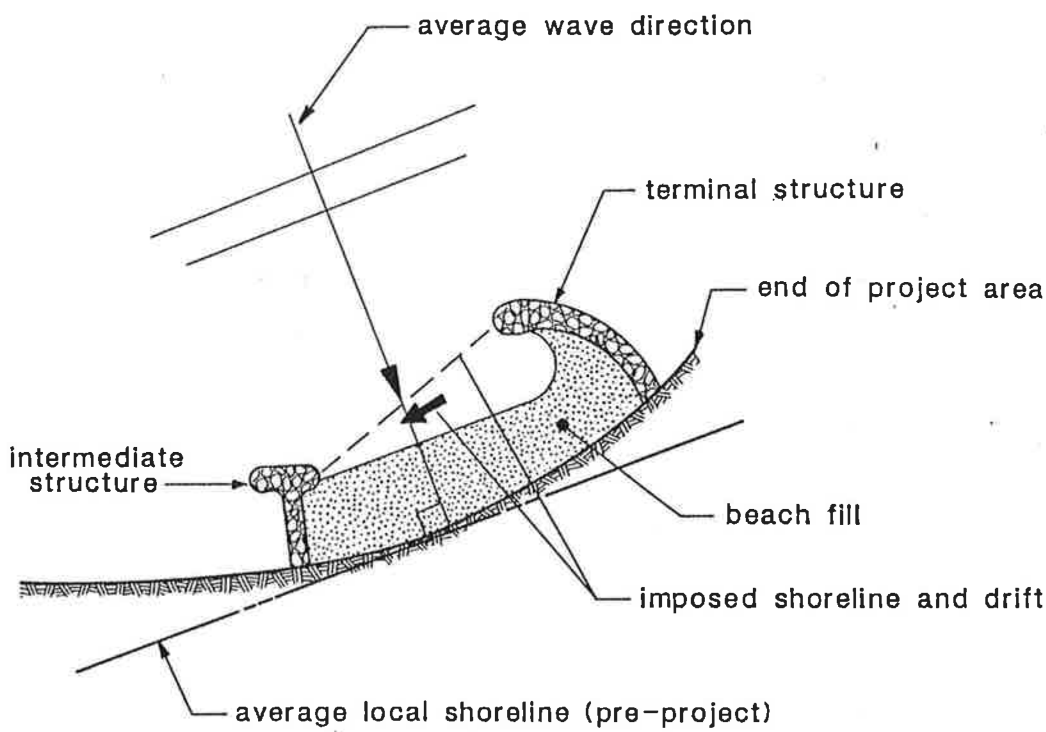

Figure 4: Artificial headland orientation selected to impose a desired net drift direction along a beach fill section.

The design berm elevation of the beach fill is +6 ft NGVD (4.4 ft above MHW). The crest elevation of the stabilizing strucutres varies between +4 and +5 ft NGVD. The pre-project "beach" berm (or scarped upland) varied in elevation between about +4 and +7 ft NGVD. The existing "beach" (or upland) within the project's fill area was excavated to +2 ft NGVD prior to construction of the rock structures and the subsequent placement of the aragonite fill. Interestingly, a minor coarse sand beach continually accreted along the excavated shorefront before the aragonite was placed. The source of this material is uncertain (although it is likely derived from the nearshore profile).

In order to create a minimum dry beach area suitable for recreation -- given the project's seaward size restrictions due to environmental concerns -- the owner agreed to excavate portions of the limerock upland to accommodate the beach restoration project. The resultant design produced a sinuous excavation plan, armored by upland revetment, with large pocket bays of beaches between the

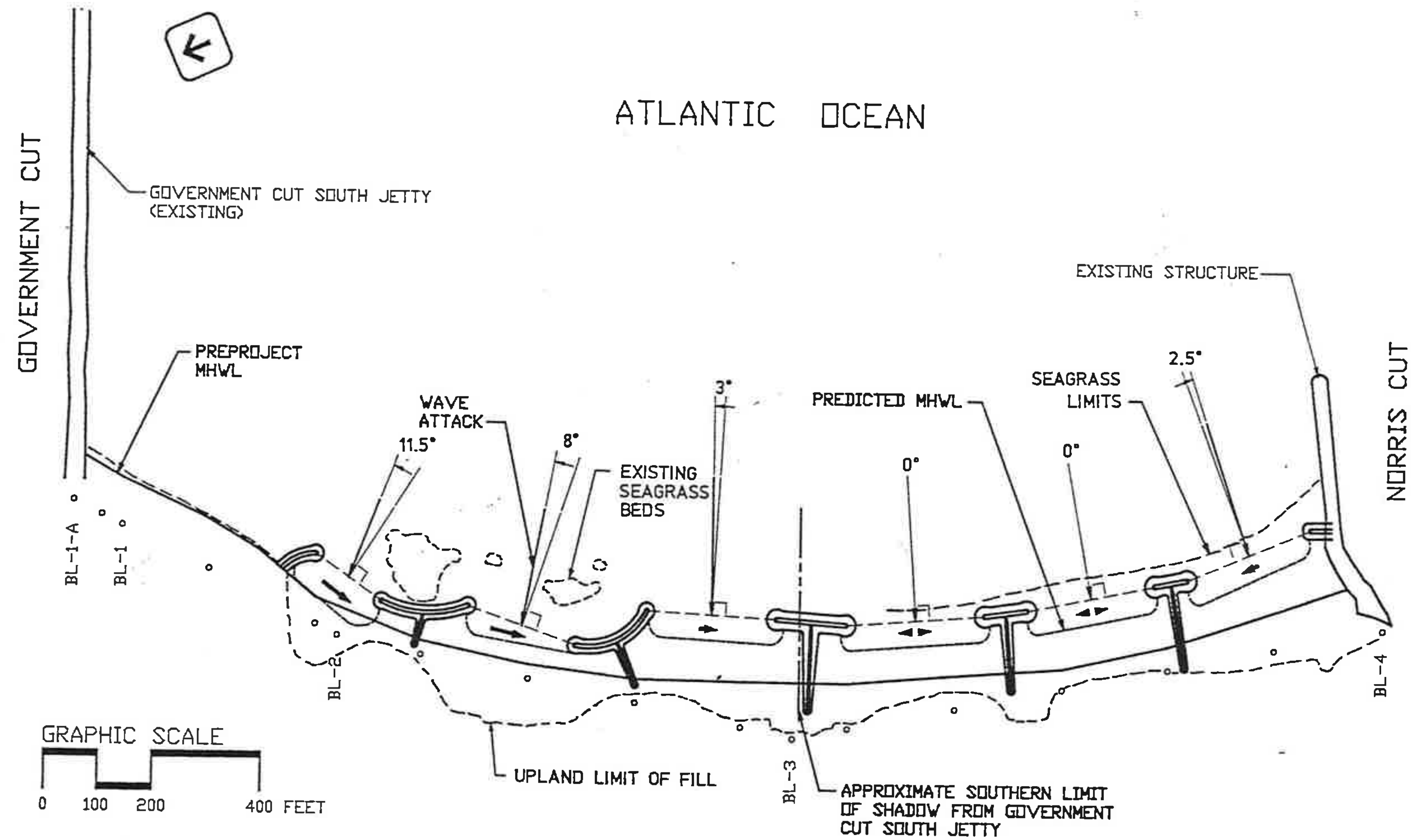

Figure 5: Plan of beach restoration project at Fisher Island, Florida.

stabilizing structures. The landward end of these structures were, in turn, attached to the revetment but buried by the placed fill to allow lateral access along the restored beachfront.

Median grain size of the limited, pre-project "beach" material varied from 0.24 mm to 0.21 mm along the north/central and south shoreline segments, respectively. A preliminary estimate of the median grain size of the aragonite fill is about 0.27 mm with 3% finer than 0.107 mm and less than 0.5% finer than 0.074 mm.

Figure 5 additionally depicts the predicted post-project equilibrium shoreline, to which the actual post-project shoreline orientation will be compared during this paper's public presentation. At this writing (January, 1991), project construction is 50% complete. Likewise, results will be presented which describe preliminary environmental and performance data relative to the aragonite's durability, dissolution, turbidity, construction slope, equilibrium slope, benthic impacts, etc.

SUMMARY

In summary, the shorefront improvement project at Fisher Island includes the use of aragonite beach fill and "tuned" structures (both of which are novel in the United States) in order to practically restore a beach with a reasonably acceptable project life, and to do so with minimum impact to nearshore biological communities. The project offers a unique opportunity to study in prototype scale the performance and impacts of both oolitic aragonite and highly-tuned structures in beach restoration projects.

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