The Marble beaches of Tuscany.

THE MARBLE BEACHES OF TUSCANY*

KARL F. NORDSTROM, ENZO PRANZINI, NANCY L. JACKSON, and MASSIMO COLI

ABSTRACT. Beach-nourishment operations designed to replace sediment lost through erosion change the identity and meaning of coastal landscapes. Seven beaches in Tuscany, nourished with marble-quarry waste, reveal how an industrial byproduct is naturalized by particle rounding and sorting and can become a positive symbol of human-altered nature. The marble was placed on formerly sandy beaches, resulting in different grain size and color of sediments, beach morphology, and value for human use. The abrasion rate of marble makes the nourished beaches unsatisfactory when viewed solely as protection structures, but the rapid particle rounding and aesthetic appeal of marble increase the acceptability of the beaches for recreation. *Keywords: abrasion, beach nourishment, gravel beach, mine waste, shore protection, Tuscany.*

Nearly all landscapes bear the imprint of humans, and the dichotomy between the ways human and natural landscapes are interpreted and managed is breaking down (Graf 2001; Vogel 2003; Heyd 2005). The likelihood that a landscape will be subject to direct human manipulation is related to economic or social objectives. These objectives may be incompatible with environmental objectives in creating landforms as functional and sustainable natural systems (Saurí-Pujol and Llurdés i Coit 1995; Graf 2001). One of the most vulnerable natural landscapes is a sandy coast, where beaches have great recreational and commercial value and where landforms are easily reshaped or replaced by earth-moving machinery.

Construction and protection of human facilities close to the water on eroding coasts is eliminating many beaches. Concurrently, the intensity of beach use is growing, placing greater demand on remaining beach space and increased economic value on beaches (Beachmed, 2004; Reid and others 2005). The principal solution for managing erosion on coasts developed for tourism is artificial beach nourishment (Hanson and others 2002). The beach may be replaced, but the high cost of obtaining, transporting, and emplacing fill material often leads to use of sediment that differs considerably from native sediment in provenance or size (Pacini, Pranzini, and Sirito 1997; Nordstrom 2000).

Engineering works can be catalysts for reconfiguring the relationship between nature and humans (Kaika 2006), but considerable debate occurs about how nature should be perceived and appreciated (Schein 1997; Crist 2004; Ross 2005). Many beaches nourished with sand are mechanically graded into flat recreation platforms.

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These artifacts are accepted as proper images of beaches in coastal resorts and replicated throughout the world (Nordstrom 2000). The result is a loss of the regional distinctiveness of beaches and their relationship to the local environment. Ways can be found to recapture or improve the landscape image of a coastal region through careful selection of beach fill (Arba and others 2002). This opportunity is maximized where the fill material is attractive to beach users and associated with the local environmental or cultural heritage.

Most assessments of beach-nourishment operations focus on the rate at which sediment is eroded, the degree to which the new beach functions as a protection structure (Houston 1991; Swart 1991; Pilkey 1992; Kana and Mohan 1998; Browder and Dean 2000), or the significance of nourishment operations to biota (Rakocinski and others 1996; Peterson, Hickerson, and Johnson 2000; Rumbold, Davis, and Perretta 2001; Speybroeck and others 2006). Evaluations are also required of the way fill sediment that differs dramatically from the previous beach sediment alters the identity of coastal landscapes.

The form, composition, and human use of beaches can change based on shifts in economic practice within a given region, but little attention is placed on this aspect of cultural heritage when selecting beach fill materials (Nordstrom, Jackson, and Pranzini 2004). In this study we evaluate the way in which marble gravel, as an industrial by-product, can become a new and seemingly positive symbol of human-altered nature and how the concept of heritage tourism, applied to the human infrastructure at mine sites (Balcar and Pearce 1996; Edwards and Llurdés i Coit 1996; Ruiz-Ballesteros and Hernández-Ramírez 2007), can be applied to the by-product of mining as a natural resource. We focus on human-use value of the resulting beaches, although we acknowledge the great positive and negative influence that beach nourishment has on natural values (Milton, Schulman, and Lutz 1997; Peterson, Hickerson, and Johnson 2000; Speybroek and others 2006).

Gravel as Beach Fill

Guidelines for nourishing beaches recommend use of sediment that is similar to native materials (Nelson 1993; National Research Council 1995; Peterson, Hickerson, and Johnson 2000; Dean 2002), but where gravel is available and inexpensive, it may be used to nourish sandy beaches, creating a different morphology, habitat value, aesthetic appeal, and evolutionary history (Pacini, Pranzini, and Sirito 1997; Arba and others 2002; Nordstrom, Jackson, and Pranzini 2004). Gravel beaches are more stable than sand beaches due to larger particles that are less easily entrained and rough surfaces that dissipate waves energies (Carter and Orford 1984). The greater space between the interstices of gravel particles increases percolation of water, leading to greater transport capacity on the wave uprush than backwash, enhancing deposition on the upper beach (Everts, Eldon, and Moore 2002; Austin and Masselink 2006). This deposition creates a higher, steeper foreshore (zone reworked by wave uprush and backwash) on gravel beaches and more conspicuous microtopography, including storm berms and cusps.

Gravel placed on a sandy shore may only temporarily change the way the beach evolves. Sand can infiltrate the pore spaces in the gravel, creating a surface gravel layer with sand and gravel below (Carter and Orford 1984). As sand is added to the gravel—which occurs relatively soon after gravel placement—or as the gravel abrades —a longer-term process—the beach will behave more like a sand beach hydrodynamically (Carter and Orford 1984; Mason and Coates 2001). Adding small amounts of gravel to a sand beach may be counterproductive because isolated gravel particles may be readily entrained from, and moved across, a finer-sized bed (Carter and Orford 1984; Aminti, Cipriani, and Pranzini 2003), and gravel will be rapidly displaced alongshore or washed onto the backshore (the portion of beach that is only under the direct influence of waves during the largest storms). There, it remains as a conspicuous, intrusive element. The amount of gravel placed on a sand beach and the elapsed time are critical in the form, function, and aesthetic appeal of a beach nourished with gravel.

Much of the gravel used in nourishment projects is from upland sources, including quarries (Pacini, Pranzini, and Sirito 1997; Shipman 2001), requiring evaluation of its chemical composition, angularity, and sorting. Nourished beaches may be considered acceptable or unacceptable to recreational users, depending on the degree to which the altered beaches match the characteristics of the original ones or have an appeal of their own. Using gravel fill on a beach formerly composed of sand will change the use of the beach for recreation. Beach users may dislike the coarse, angular sediments, steep foreshore slopes, and high berms that make access difficult.

Interest in nourishing beaches with gravel is increasing, but technical information on the geomorphic and engineering aspects of gravel and of mixed sand and gravel beaches only recently appeared in the literature (Pacini and others 1997; Blanco and others 2003; Cammelli and others 2006). Despite the increasing body of knowledge concerning the morphodynamics and habitat characteristics of gravel beaches (Walmsley and Davey 1997a, 1997b), and interest in mixed sand and gravel beaches (Mason and Coates 2001; Jennings and Shulmeister 2002; Pontee, Pye, and Blott 2004; Horn and Walton 2007), few studies exist of beach-nourishment projects that place gravel on sandy coasts. In this article we examine the addition of marble gravel to sand beaches and to locations where sand beaches once existed but were lost due to erosion. Marble beaches were selected for study because they represent a conspicuous departure from natural conditions. Marble beaches are not likely to form and survive under natural conditions. Marble is relatively rare in nature, and, as a carbonate rock, it is subject to karst formation and subsurface drainage, leaving little surface runoff to deliver sediment to streams and eventually to the coast. If a marble beach did form from direct wave erosion of a marble formation, it would be subject to more rapid loss from abrasion than would many of the more resistant rock types found on most gravel beaches.

The study area is the coast of Tuscany between Marina di Carrara and Marina di Pisa (Figure 1). This region is one of the most famous sources of marble quarry

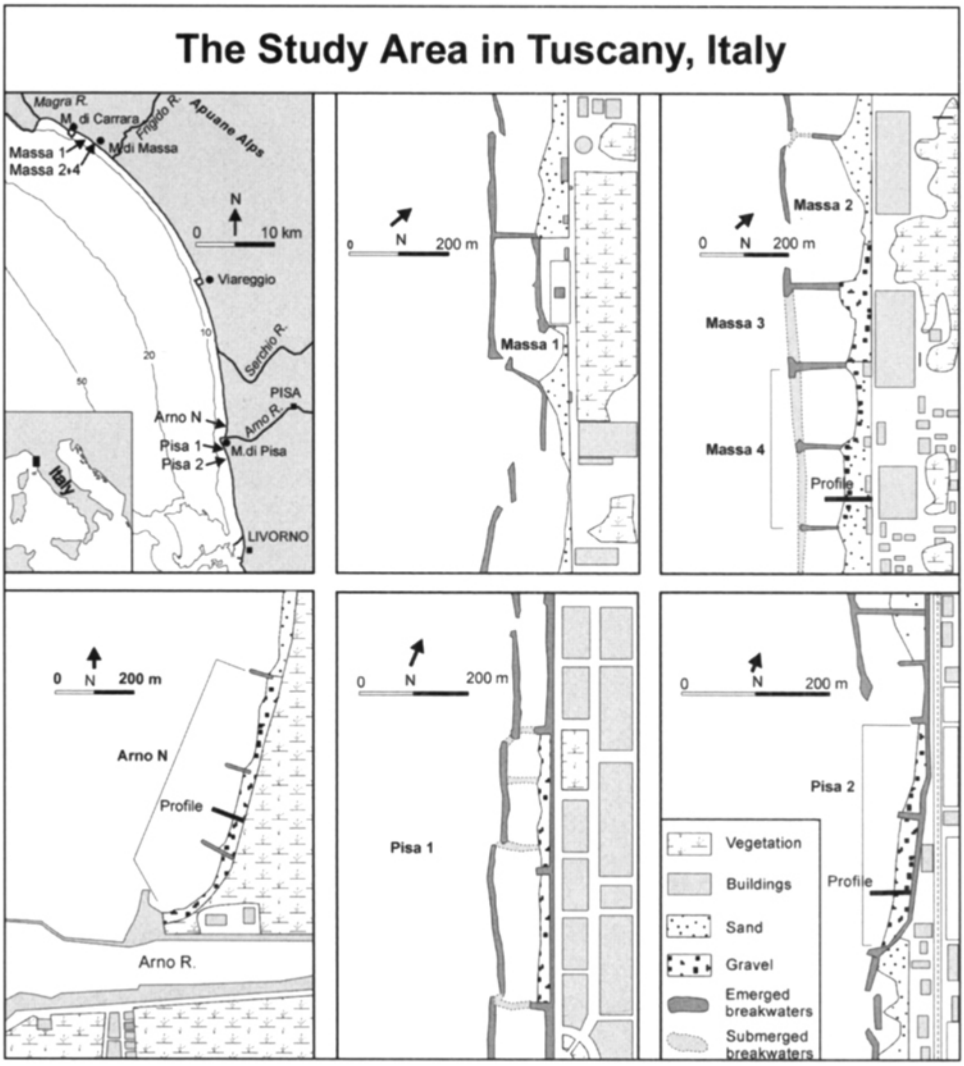

FIG. 1—Our study area in Tuscany, Italy. Field data on beach morphology and sediment characteristics were gathered at sites identified by boldface type. (Cartography by Enzo Pranzini)

rock in the world. Marble gravel has been used as fill material at seven different sites under several scenarios, including protection of shorefront roads (Massa 1, 2 and 3), protection of sand beaches managed and groomed, largely by raking, for intensive recreation (Massa 4), protection of a nature reserve unaffected by recreational use (Arno N), and creation of new beaches seaward of seawalls in a resort community, where the previous beaches were eliminated by wave erosion (Pisa 1 and 2). We extend the temporal and spatial frameworks of previous case studies conducted on marble beaches at Massa 4 and Pisa 2 (Aminti, Pelliccia, and Pranzini 2002; Cammelli and others 2006), and we place those physically based evaluations within a broader cultural framework.

The Coastal Setting

The greatest tidal range along the Tuscany coast is 0.38 meters at Livorno (see Figure 1). Wave data from a gauge in 70-meter-deep water off Marina di Massa reveal that deepwater waves are less than 1.0 meter during 74.7 percent of the year and exceed 4.0 meters only 0.37 percent of the year. The highest waves approach from 230 to 240 degrees, with limited directional dispersion. Net longshore transport rate is to the south and is calculated as 115,300 or 230,000 cubic meters per year at Massa 4, depending on the equation used (Aminti, Pelliccia, and Pranzini 2002). All of the beaches nourished with marble gravel are within groin compartments. These groins, and the many other shore-protection structures, divide the compartments into isolated drift cells and limit sediment exchanges between them.

Natural beach sands are primarily quartz, feldspar, serpentine, garnet, and epidote (Garzanti and others 2002). The amount of sediment delivered to the beaches by streams differs through time, based on human activity in the hinterlands. Population increase from the late Etruscan period until the nineteenth century resulted in deforestation, which delivered much sediment to rivers and thence to the beaches. Reforestation, river damming, and riverbed quarrying since the mid–nineteenth century have reduced sediment inputs (Pranzini 2001). Beginning in the mid–nineteenth century, elimination of malaria, construction of railways, expansion of harbor facilities, rise in fashion of seaside holidays, and reduction in working hours increased use of the shorefront and development of coastal infrastructure. Towns with the prefix "Marina di" were established as resorts for towns farther landward. Marina di Pisa, the oldest resort on the Tuscan coast, began as a resort for Pisa in the nineteenth century. Marina di Massa began early in the twentieth century, and a 1904 map reveals only a few scattered houses near a pier built to load marble blocks.

Erosion of the shoreline at Marina di Massa increased following construction of a harbor at Marina di Carrara that intercepted the southerly longshore sediment transport, leading to construction of many breakwaters, groins, and seawalls. The erosion rate in unprotected areas was about 4 meters per year between 1985 and 1998. The shoreline at Marina di Pisa retreated more than 100 meters from 1880 to 1920 due to reduction in sediment delivered by the Arno River. Construction of breakwaters and seawalls south of the mouth of the river, beginning early in the twentieth century, stopped landward retreat, but these structures did not prevent elimination of the subaerial beach. The undeveloped segment north of the Arno River (Arno N) remained unprotected by structures and retreated more than 1.3 kilometers in the last 120 years while maintaining a beach through progressive erosion of the upland.

The Tuscan coast is a popular tourist destination, but loss of beaches reduces the viability of resorts, and Marina di Pisa has already reached the stagnation stage of the resort cycle identified by R. W. Butler (1980). The loss of recreation space, combined with threats to human investments from erosion, increased the demand for beach nourishment. Sand would have better replicated the natural beach materials, but gravel was preferred at Massa 3 and 4 and Pisa 1 and 2 because coarse material produces a wider, higher subaerial beach than finer sediment for a given volume.

Legal restrictions on mining sand provide an additional deterrent to use of sand as fill. The riverbed quarries in Tuscany were closed in the 1980s as a result of prohibition of riverbed dredging in accordance with the environmental policy identified in Regional Law 52 of 1982, which defines parks and protected areas. The few quarries in the alluvial plains outside the riverbanks do not provide enough sediment, and little sand is now available in the region. The only recent beach-nourishment project in northern Tuscany that used sand as fill was in 2006, when sediment from the Po River plain 130 kilometers away was deposited at a cost of €21 per cubic meter. Even this high price was more favorable than expected, because the trucks that were used carried quarry stones to northern Italy and would have come back empty. It is difficult to find sand that costs less than €30 per cubic meter near the site unless a new opportunistic source, such as from channel dredging, becomes available. Use of nearshore sediments for beach fill is not favored by the regional (Tuscan) government because of the potential for the greater water depth to increase wave energy onshore. A preliminary research project was conducted in 1999–2000 to identify sand deposits farther offshore at water depths of up to 130 meters. More recently, the regional government spent €2 million for more extensive research on deposits on the whole Tuscany shelf. Acceptable volumes and grain sizes were identified off Marina di Massa, but analyses required by the law are expensive and will cost about €2 million for four borrow sites and take one or two years. Even then, these sands may not be used, for the Ministry of the Environment may not authorize the dredging because the offshore zone between Elba Island and the Ligurian coast is a whale sanctuary.

Marble gravel is a viable and inexpensive option for beach nourishment because it is available locally as waste material at quarries and processing plants. Carrara marble is a lithostratigraphic formation of the Apuane Alps (see Figure 1), laid down in the Early Liassic and modified by tectonic metamorphic deformation during the Tertiary (Coli 1989). Differences in the amount of impurities and the texture of the protolith during the tertiary tectometamorphic deformation resulted in two basic types of marble: pure white marble with grains of 0.6–0.8 millimeters, and veined gray marble with iron and limestone impurities and smaller grains (0.3–0.7 millimeters), which make it more resistant to abrasion. The marble quarries were first exploited in the first century B.C. (Baroni, Bruschi, and Ribolini 2000), and deposits of quarry debris have accumulated ever since, about half of them in the past fifty years. Both Carrara and Massa (the latter meaning "boulder" in Italian) are marble-processing centers. Marble is so plentiful locally that it is used for construction of groins, jetties, and curbstones.

About 4.5 million tons of marble are cut yearly, with 1.2–1.5 million tons used as ornamental stone, 2 million tons used as powders for paints and cosmetics, and 0.8 million tons for construction aggregate. Marble that is considered unsuitable for industrial use consists of blocks smaller than 1.5 by 1.8 by 2.5 meters that cannot be cut efficiently using mechanical saws. These fragments remain at the quarry. Smaller rectangular and triangular fragments, representing odd sizes or breakage during cutting remain as waste at processing plants, along with imported exotic rock types. Marble mined from quarries is used more efficiently now than in the past, but about 80 million tons of debris remain in the Carrara quarry and an additional 40 million tons in the surrounding region. Accumulation of marble waste at the base of the quarries is a hazard (Baroni, Bruschi, and Ribolini 2000), so its removal is desirable.

Blocks of cuttable marble cost about €200–600 per ton, but fragments cost less than €3 per ton, excluding tax and transportation costs. The expense of using marble as a fill material is largely a function of the latter. Pisa 2 is about 65 kilometers south of the processing plants in Marina di Massa and is near the location where the cost of alternative sources of fill, including limestone from quarries farther south, nearly balances the cost of marble fill.

Marble beaches did not exist in the Carrara region prior to artificial nourishment because the marble formations are landward of the coast, where they are not exposed to wave erosion. Marble rocks are found in local streams, but they are waste materials dumped as by-products of quarrying and processing. These sediments become rounded by stream action and look more like natural stream deposits than do the angular processed materials, but few gravel-sized particles reach the beaches by natural processes because the flat slopes of the final courses across the coastal plain limit the transport capacity of the streams.

Methods of Evaluation

The lengths of the nourished beaches were determined from aerial photographs at a scale of 1:5,000, flown 17–20 August 2003 for the Italian Ministry of Transportation. Unstructured interviews with the town engineer at Marina di Massa, the owner of the beach concession at Massa 4, and project managers for fill projects at Arno N, Pisa 1, and Pisa 2 provided details on the dates and volumes for the marble fill and subsequent use of the beaches by visitors. We observed visitor patterns on a warm Saturday in May 2006 at Pisa 1 to obtain insight into their preferences for gravel or sand beaches.

We evaluated the ability of marble fill to become naturalized as beach material as a result of wave reworking using field data on beach morphology, grain size, and degree of roundness of surface sediments at three sites. The sites were chosen because they had previously been evaluated (Aminti, Pelliccia, and Pranzini 2002; Cammelli and others 2006; Fanini and others 2007) and because they represented three different types of shore: a sandy recreational beach (Massa 4), a nature protection area (Arno N), and a resort with no beach (Pisa 2). Reconnaissance-level investigations were conducted at the other four sites.

Topographic surveys were conducted at the three representative sites during calm conditions along a shore-perpendicular transect near the middle of groin compartments using a total station. Water-level changes on the beaches are driven by winds and waves, not tides, so process zones are defined by levels of storm activity, represented by breaks in slope or surface gravel layers. Representative surface sediment samples were gathered along each transect within these process zones, which included: the active foreshore near the upper limit of daily swash uprush during nonstorm conditions; the upper foreshore reworked by the most recent small storm; the middle of the zone representing the foreshore during large storms (called "midstorm"); and just below the upper limit of swash uprush during large storms, revealed by the uppermost recent wrack line (called the "storm-swash sample"). Where both sand and gravel bands were located within these zones, the widest band containing gravel was sampled. Gravel in some of these bands was patchy and contained some sand. Some process zones contained no gravel and are represented only by a sand sample. Additional samples were gathered on the backshore at Massa 4 to reveal the influence of raking and on the overwash deposit (sediment delivered landward of the upper ridge) at Arno N to show the characteristics of sediments displaced from the foreshore before being reworked by breaking waves and swash. No comparable sample was gathered at Pisa 2, where the seawall constrains development of the beach landward.

Percentages of marble and degrees of rounding of sediment samples were visually estimated. Using the rounding criteria provided by William Krumbein (1941), samples were placed in one of ten classes using a coefficient varying from 0.1 (least rounded) to 1.0 (most rounded). They were then mechanically sieved using half-phi (ϕ) size intervals (where $\phi = -\log_2$), and size fractions were used to determine mean and sorting (standard deviation). Estimates of the grain sizes on the four beaches not evaluated in detail were made by measuring the intermediate width (B axis) of representative particles.

Rates of rounding and weight loss of crushed white and gray marble were compared with crushed gravel from the most suitable alternative locally available fill material (limestone) and the hardest of the commonly occurring local rocks (basalt). Gravel crushed by processing plants has an initial roundness value of about 0.3. The time required for sediments to become rounded in the field is difficult to evaluate because particles are mobile and their residence times in the active foreshore cannot be determined. Accordingly, a relative time was determined by comparing rate of rounding and weight loss of gravel of different mineralogies in the laboratory using a commercial rock tumbler. In each case, a 250-gram sample of 10–30-millimeter-diameter particles was run at 50 gyres per minute in ten-hour increments for forty hours.

Characteristics of Sites Nourished with Marble

The small projects at Massa 1 and Massa 2 involved dumping gravel waste to protect the coastal road rather than to function as a beach (Table I) . No beach users were expected, and the sediment used was the nearest available material that was coarse enough to be stable. Massa 3 was nourished with sand and gravel. The gravel fraction of these three sites is not especially attractive because the marble is mixed with rocks of other mineralogies and with tabular cuttings from processing plants.

The fill at Massa 4 is distributed over two groin compartments (Figure 2). A fill operation in 1999 placed pure marble gravel on a preexisting sand beach, widening the beach by 7 meters and creating a new, 3.5-meter-high gravel berm (see Table I). This new beach had a steep slope that interfered with recreational use, so, in May 2000, finer-sized crushed marble was emplaced to try to create a less permeable beach with a flatter slope (Aminti, Pelliccia, and Pranzini 2002).

Concessionaires manage both beach compartments at Massa 4. They rent beach space to tourists, giving the beaches great economic value and providing incentive to groom them frequently to make them more attractive. One of the most conspicuous actions was manual removal of the cobbles and largest pebbles from the fill after it was placed on the beach. One concessionaire stated that 100 truckloads of large particles were hauled away from the beach. Coarse particles delivered to the sandy backshore are still removed by hand: The largest particles are eliminated from the beach environment entirely, and the smaller particles are thrown back onto the lower foreshore. Concessionaires reshape the beach by piling sand up to create a protective dune dike in winter and grading it flat and raking it in summer to create a broad recreation platform.

TABLE I—CHARACTERISTICS OF NOURISHED SITES AND GRAVEL FILL ON TUSCANY BEACHES

SITE	LENGTH (m)	NUMBER OF GROIN COMPARTMENTS	YEAR OF FILL	AMOUNT OF FILL (m^3)	SIZE RANGE OR MEAN (mm)[a]	MARBLE (%)
Massa 1	100	1	2003	4,000	3–120	40
Massa 2	325	1	1998	4,000	30	70
Massa 3	170	1	2000	4,000	30–70	50
Massa 4	380	2	1999	18,200	30–70	100
Massa 4	380	2	1999	2,000	3–7	100
Massa 4	380	2	2000	10,400	0.8	100
Arno N	647	3	2001	45,700	50	100
Pisa 1	480	2	2003	48,000	16	100
Pisa 1	240	1	2006–2007	36,000	40–70	100
Pisa 2	330	2	2001–2002	28,000	40–200	90

[a]Sizes are presented as a range or as a mean. depending on the contractor's report.

The gravel on the surface of the active foreshore at Massa 4 and the gravel bands deposited higher on the beach by storms are well sorted and mostly marble (Table II; see also Figure 2). The remainder of the beach is the original sand that retains its form and function, with a wider, flatter profile than the those of the primarily gravel beaches at Arno N and Pisa 2 (Figure 3). Gravel on the upper foreshore and backshore of Massa 4 is well mixed with the sand, partly because concessionaires rake the beach. The gravel particles are nearly inconspicuous in the sand matrix, and the pure-sand fractions contain no marble (see Table II).

The site at Arno N is not open for beach recreation, so the nourished beach has value solely as protection for a freshwater marsh and forest landward of it. Marble

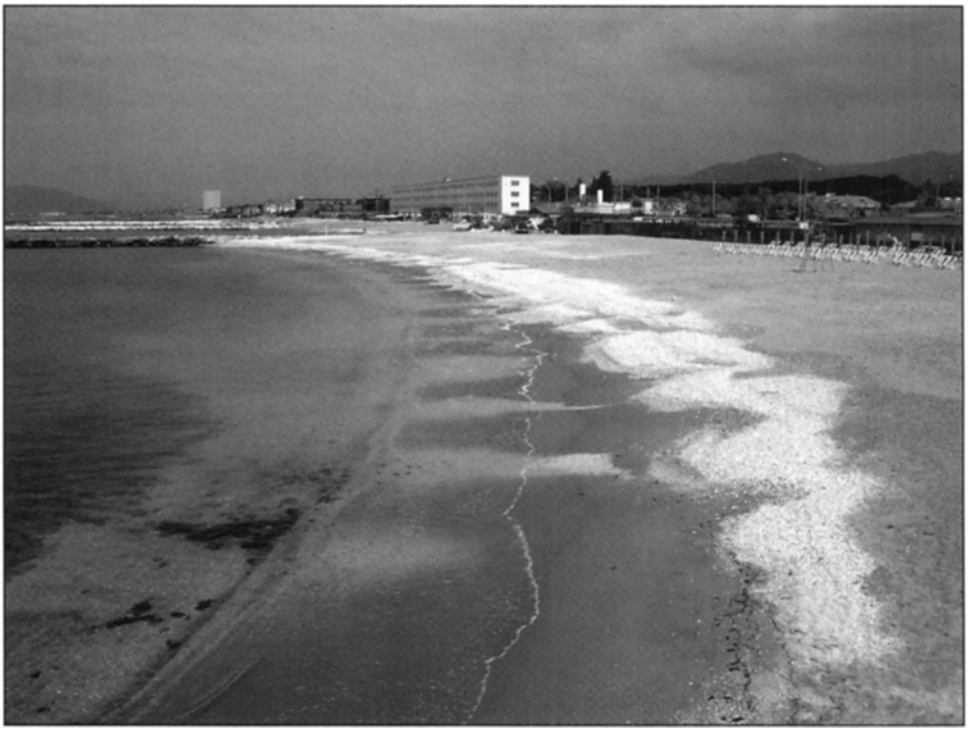

FIG. 2—The beach at Massa 4 in May 2006, showing the lower sand and upper gravel portions of the active foreshore. Sediment samples for this zone were taken in the gravel band (see Table II and Figure 3). (Photograph by Karl F. Nordstrom)

gravel from quarry waste, subsequently crushed in processing plants, was placed over an existing sandy beach. The beach undergoes rapid transgression, and the topographic profile reveals a low washover fan subsequently covered with driftwood piled up by storm swash (see Figure 3). The gravel is conspicuous on the surface of all of the beach except the upper foreshore (see Table II). The gravel on both the beach and the overwash platform is less well rounded than is that in Massa 4 and Pisa 2, where managers return gravel to the active foreshore. The overwashed sediments are more angular than the foreshore sediments and will retain their angular appearance until beach retreat brings them into the zone of wave reworking. The fill originally was angular, with a roundness value of 0.3. The 0.5 values for the overwashed sediments indicate that some rounding occurred before they were delivered to the inactive overwash fan (see Table II). Plans are now being evaluated to renourish the beach with sand that may become available from dredging of the access channel to the port at Viareggio (see Figure 1).

The nourishment operation at Pisa 1 placed pebble-sized marble seaward of a seawall within two groin compartments protected by detached offshore breakwaters (Figure 4). The sediments came from a commercial gravel-crushing plant and were angular but well sorted by running them through screens. The orientation of

TABLE II—CHARACTERISTICS OF SURFACE SEDIMENT SAMPLES GATHERED WITHIN THE WIDEST BAND OF GRAVEL WITHIN EACH PROCESS ZONE ON TUSCANY BEACHES

SITE	GRAVEL (%)[a]	MARBLE (%)[b]	ROUNDING (coef.)	MEAN (mm)	SORTING (ϕ)
Massa 4					
Active foreshore	96	75	0.7	7.37	0.89
Upper foreshore	0	0	—	0.34	0.41
Midstorm foreshore	100	75	0.8	9.16	0.35
Storm swash	100	60	0.7	26.32	0.59
(Backshore)	0	0	—	0.32	0.56
Arno N					
Active foreshore	100	100	0.6	41.02	0.17
Upper foreshore	10	10	0.6	0.50	1.14
Midstorm foreshore	100	100	0.6	46.53	0.12
Storm swash	100	100	0.7	51.81	0.34
(Overwash)	100	85	0.5	60.63	0.11
Pisa 2					
Active foreshore	100	50	0.8	20.76	0.38
Upper foreshore	100	30	0.8	42.68	0.24
Midstorm foreshore	100	90	0.8	34.40	0.40
Storm swash	100	90	0.8	46.17	0.41

[a]Percentages of gravel reflect the amount of gravel relative to the total sand/gravel sample.
[b]Percentages of marble reflect the amount of marble relative to other types of gravel.

the nourished beach changed from an alignment parallel to the seawall just after construction to an angle more aligned to the dominant onshore wave direction, from the northwest. The beach to the north of each groin compartment thus became narrow (see the background in Figure 4), and gravel was washed onto the shorefront road landward of it about twice a year during significant breaking wave heights of about 4 meters. The southern compartment was nourished with gray marble in the winter of 2006/2007, creating a platform more than 40 meters wide that is expected to be reworked by waves into a high crest far enough seaward to prevent gravel from being washed onto the road. The gravel in both compartments is 100 percent marble, creating an impressively bright beach in the central business district (see Figure 4).

The operation at Pisa 2 placed gravel seaward of a seawall (Figure 5). The fill material consisted of tabular, rectangular, and triangular cuttings left over after marble was cut from thin, processed sheets, creating unnatural shapes on the beach. The initial fill material was dumped in the Frigido River before being collected and placed on the beach, and the tabular particles were partially rounded by stream processes.

Sand appeared in the gravel matrix within two months of the end of the nourishment. The same process occurred at Massa 2 and Pisa 1 soon after gravel was emplaced. The sand apparently came from offshore rather than alongshore, because these sites are isolated from adjacent beaches by groins. The beach at Pisa 2 is now evolving as a mixed sand-and-gravel beach. The sand exists as a gently sloping

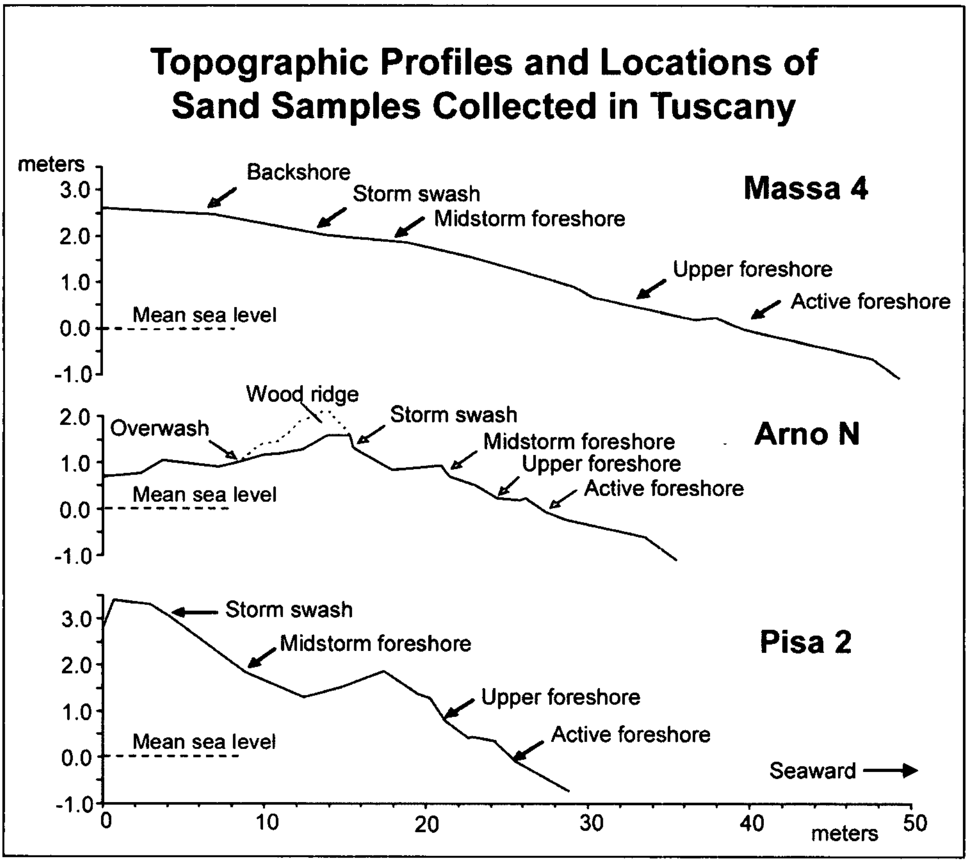

FIG. 3—Topographic profiles and locations of sand samples identified in Table II. Arrows identify the locations of sediment samples. (Graph by Karl F. Nordstrom)

lens within the gravel, outcropping near sea level but buried below the gravel at higher elevations (see Figure 5 and Table II).

The beach at Pisa 2, like Pisa 1, became realigned to the dominant waves, resulting in narrowing of the northernmost part of the fill and deposition of gravel on the road landward. Grading is conducted at Pisa 2 to create a gentler gradient for beach access and to place the berm crest farther seaward and prevent deposition of gravel on the road. Grading also puts angular sediments back in the active swash. The gravel is well rounded because of prior abrasion in the river, transportation and reworking of sediments as the fill became realigned to the dominant wave direction, and reinjection into the active swash zone by bulldozing. The gravel is well sorted (see Table II), presumably because the well-rounded sediments are readily moved to their equilibrium position on the profile. Plans are now being made to increase the volume of the beach by adding more than 50 cubic meters of gravel per meter of beach. The plan is to use gray marble or some other harder rock because the volume loss from abrasion of white marble is believed to be too great.

FIG. 4—The marble beach in the more southerly of the two beach compartments at Pisa 1 in May 2006. The beach near the marble groin in the background narrowed after the fill, and gravel is thrown onto the road during storms, requiring use of earth-moving equipment to return overwashed sediment to the beach. (Photograph by Karl F. Nordstrom)

FIG. 5—The beach at Pisa 2 in May 2006, showing the sandy foreshore in the swash zone. (Photograph by Karl F. Nordstrom)

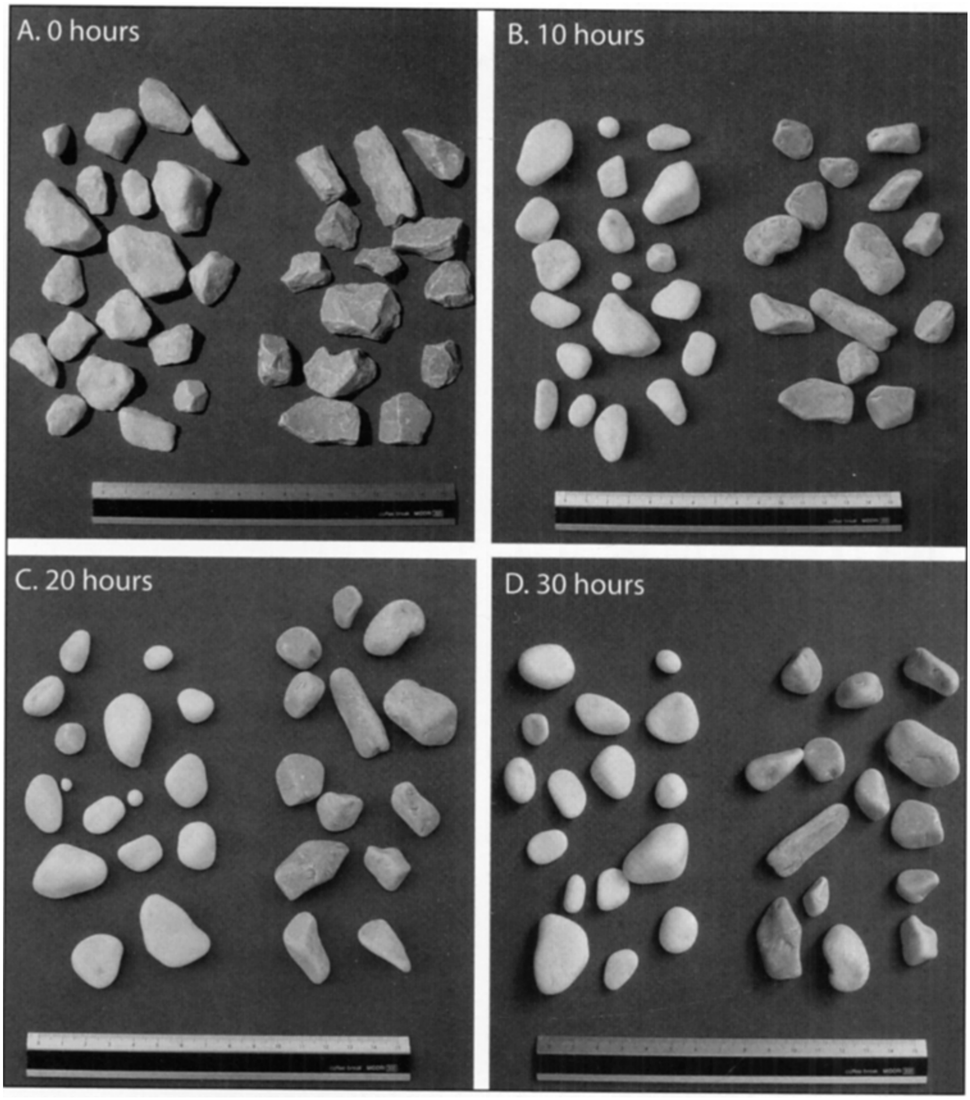

FIG. 6—Rounding of white (left) and gray (right) gravel in tumblers, evaluated at ten-hour intervals. (Photograph by Enzo Pranzini)

DURABILITY OF MARBLE

Tumbling experiments revealed that crushed white marble rounds more rapidly than does gray marble (Figure 6), changing from an initial roundness of 0.3 to a roundness value of 0.8 after thirty hours. Gray marble becomes 0.6 after thirty hours; limestone and basalt become 0.6 and 0.5, respectively, after the same length of time. Weight loss of marble is rapid relative to that of the other rock types (Figure 7). More than half of the weight of white marble is lost in forty hours, compared with less than 30 percent for gray marble and less than 8 percent for basalt. The durability of basalt gives it great value for erosion protection, but its slow rate of rounding

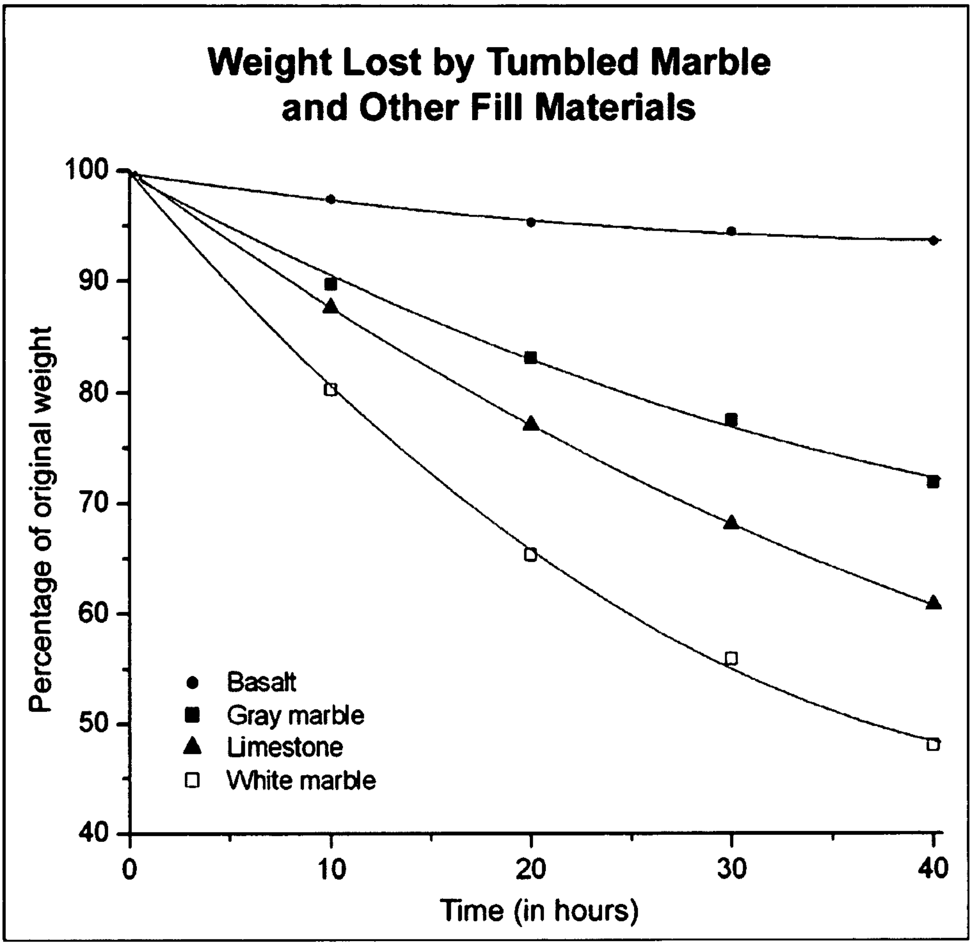

FIG. 7—Loss of weight of crushed marble and alternative fill materials in tumblers, evaluated at ten-hour intervals. (Graph by Enzo Pranzini)

and darkness that affect aesthetics and surface temperature make it unsuitable for beach recreation. The rapid abrasion rate of marble was not considered in the earliest projects using marble fill, but abrasion rate was considered for the most recent project at Pisa 1 and the planned project at Pisa 2.

User Considerations

The marble gravel was not selected as beach fill because of its perceived value for recreation, but its acceptability for recreational use is critical to decisions about future operations. Marble gravel beaches may be compared with sand beaches in terms of grain size, which results in different morphology and stability, and with other gravel beaches in terms of mineralogy, which results in a different color, rate of abrasion, and potential for pollution. Like use of other types of gravel fill on sandy coasts, the advantages include adding topographic diversity and new user options, such as listening to the sound of gravel rolling in the swash, collecting interesting rocks, throwing rocks into the water, or using them as building blocks to create an alternative to sand sculptures. Gravel beaches are good for wave watching because the steep, permeable beach quickly dissipates swash uprush, and beach users can sit close to the breaking waves without being splashed by the swash.

Gravel does not hold water or facilitate capillary rise like sand, so it is a dryer platform for sitting, and it does not adhere to skin or clothes. According to the concessionaire at Massa 4, most people who do not use beach chairs prefer sitting on marble granules and small pebbles (3–7 millimeters in diameter) to sitting on sand, but sand is preferred over larger gravel.

The disadvantages of all gravel beaches are that the steep foreshores make vertical access more challenging, that the coarser grains make walking barefoot uncomfortable, and that beach umbrellas are difficult to emplace. The advantages of marble over other available rock types are its whiteness, which makes both the exposed surface of the beach and the water appear cleaner (see Figure 2), its cooler temperature in summer due to its high reflectivity, its roundness, thus comfort for walking and sitting, resulting from its susceptibility to abrasion, and its cachet, resulting from its use in sculpture, expensive floors, and wall panels. Visitors often collect marble from the beaches for use at their homes.

Our observations of beach use at locations where both sand and marble gravel beaches are equally accessible found more visitors on sand beaches, especially families with children, but substantial numbers of visitors use marble gravel beaches. The use of marble gravel beaches during nonpeak periods, when sand beaches are available, indicates that marble beaches are not selected only as a fallback option when sandy beaches are full but can be preferred.

Implications

The marble beaches of Tuscany are not accurate representations of wild nature; nor are they the most suitable means of protecting human facilities. The physical continuity with the past that is a desirable characteristic of a restored natural landscape cannot be achieved when beaches are nourished with marble (Elliot 1982). The marble beaches are unsatisfactory when viewed solely as protection because the sediments are too easily abraded to provide long-term protection, although the susceptibility to abrasion does help make the beach more acceptable to beach users.

Human actions can create and maintain a coastal environment in a desired condition in locations where these environments would not occur as a result of natural processes alone, but maintenance of these human-altered environments often requires ongoing human inputs (Nordstrom 2000). The most significant modifications of the morphology and grain-size characteristics of marble beaches following initial placement result from periodic nourishment to replenish losses and regrading using earth-moving equipment. Periodic nourishment is required in all beach-nourishment operations conducted on eroding shores, but it may be required more frequently on white marble beaches than on other gravel beaches because of the high rates of loss through abrasion. Regrading has occurred on selected gravel beaches to wash and sort them and help them become rounded (Pacini, Pranzini, and Sirito 1997). Regrading may be less of an issue on marble beaches because the sediments are aesthetically pleasing, are easily rounded, and become well sorted quickly (see Table II).

The return of sand from offshore following gravel placement noted at Massa 2, Pisa 1, Pisa 2 was seen elsewhere in Italy (Berriolo 1993). Results at Pisa 1 indicate that gravel can facilitate transportation of sand from offshore, even on beaches sheltered by offshore breakwaters. Losses of volume due to abrasion reduce the proportion of surface gravel relative to sand, as do the subsequent human attempts to remove larger particles and cover the gravel with sand to make the beach more suitable for recreation or habitat. Although sand may become visually dominant, marble particles will be exhumed periodically, and the tendency for marble to accumulate in bands on the surface of a sandy beach cause it to be conspicuous for a long time (see Figure 2). Gravel will only visually dominate the landscape if placed where a subaerial sand beach did not exist or in large enough volumes and frequently enough to keep preexisting sand buried (see Figures 4 and 5).

Agreement on how human-created nature should be evaluated may not be easy to reach. Marble beaches have value for tourists, but of a sort that differs from the sandy beaches that are normally associated with active recreation. The use and acceptance of an exotic material like marble as beach sediment underscore the way in which beaches become artifacts. The marble beaches may not yet be as readily accepted as the mechanically groomed, sandy beaches that are themselves poor substitutes for nature, but the marble beaches have their own appeal as tourist destinations. The beaches composed of nearly pure, wave-reworked marble have aesthetic appeal (see Figures 4 and 5), and the linkage of marble with the arts, culture, and industrial heritage of this part of Tuscany add to the interest. A case can be made for using marble to nourish the beaches at resorts like Marina di Pisa, but a rationale based on human interest is unjustified in a nature preserve such as at Arno N.

The effect of a tourist spot's image on perception, behavior, and destination choice is universally acknowledged, and the distinct attributes of a place can be used to entice demand (Chen and Uysal 2002; Gallarza, Saura, and García 2002). Revitalization of a recreational resort can occur after introduction of a new attraction offering a specialized and differentiated product (Priestly and Mundet 1998). Marina di Pisa is well positioned to take advantage of this opportunity. The marble beaches have not yet become a commodity, but given the uses made of them, they could be converted into revenue-generating recreation areas, just as their sandy counterparts have been. Regional metaphors can be created for commercial purposes (Popper and Popper 1999), and the term "marble coast" would have great drawing power. Local users of the beaches may not consider the significance of marble to the region or the link to regional economic and cultural heritage as important to their beach experience, because they are aware of the marble groins, jetties, and curbstones and therefore consider marble commonplace. Outsiders see a region differently (Popper and Popper 1999), and tourists from outside the area who put Florence and Pisa on their itinerary may be tempted by an attraction that adds beach recreation to cultural tourism.

Human-induced elements in the landscape may not be natural, but they may be acceptable if landscape values related to the history of land-use evolution and human practices in a region are conserved (Cosgrove, Roscoe, and Rycroft 1996). Part of the perceived value of a nourished beach can derive from its cultural heritage (Nordstrom, Jackson, and Pranzini 2004). Rock quarrying is a traditional industry in this region (Aminti, Cipriani, and Pranzini 2003), and marble is part of the heritage of this area of Tuscany. Contextual complexity contributes to high aesthetic value (Hepburn 2004), and information beyond what an object presents to the senses is becoming increasingly recognized as relevant to its aesthetic appreciation; this information usually includes, but is not limited to, the history of production of the object (Carlson 2000). Here is where industrial and environmental heritage can converge. The attractive image of marble, its importance in the regional economy, and its historic significance make the marble beach an evocative symbol of urban nature.

Newly nourished marble gravel beaches are distinctive because of the perceived quality of the beach material, but the rate of abrasion is rapid, and the incorporation of sand into the gravel matrix, combined, in places, with removal of the larger particles by concessionaires causes them to lose their distinctiveness rapidly. Marble beaches are likely to be perceived as special features only if marble is prominent (see Figures 4 and 5). The marble must be replaced to retain its special image and user values, but the volume of marble waste is vast. The feasibility of nourishing the marble beaches and other beaches in the area using sand from offshore sources is still being evaluated, and it is also possible that new opportunistic sources with different sediment characteristics could be used to renourish the beaches, so their sediment characteristics could change dramatically at any time. The marble beaches of Tuscany are not permanent elements of the landscape, but their temporary nature does not make them any less interesting or lessen their place in environmental history.

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