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SEASONAL SEDIMENT MIGRATION AND SEDIMENT DYNAMICS ON SANDY POINT BEACH, SAN SALVADOR ISLAND, BAHAMAS

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ABSTRACT

A study of the dynamics of Sandy Point Beach along the southwestern corner of San Salvador Island over an eighteen-month period, beginning in June, 1990, has revealed that two seasonal phases of sediment transport are operative. Based primarily on analyses of the grain-size parameters of sand samples collected from the beach in June, 1990, a northerly direction of sediment transport was detected. This is herein termed the Spring/Summer phase of transport, and it results from the energy of waves generated by the prevailing easterly trade winds. Continued profiling of the beach in December, 1990, and January, 1992, revealed that a strong southerly transport direction is dominant during the fall/winter months. The energy for this phase of sediment transport comes from northwesterly storms. It appears that during such events, large amounts of sediment can be moved rapidly toward the southern end of the beach.

INTRODUCTION

The Sandy Point Beach, located along the southwestern corner of San Salvador Island, is probably the most dynamic large beach on this island. This study was designed to investigate the dynamics of this beach, and measurements and observations have been made over an eighteen-month period, beginning in June, 1990. The findings have proved useful in recognizing two distinct, seasonal phases of sediment transport.

Field research was conducted during four expeditions, beginning in the months of June and December, 1990, as part of a thesis research project (Loizeaux, 1991), and continued in July 1991, and January 1992. While many geologic studies have been conducted on San Salvador, few have dealt with modern beach sediments, and only one other, concurrent beach study has considered the short- and long-term dynamics of a single beach on this island (Brill, 1991; Brill et al., this volume). Previous studies on San Salvador relevant to this project include modern nearshore and beach sediment analyses by Lee et al., 1986, and Clark et al., 1989.

The field study was initiated by first establishing a 1.925 km base line along the Sandy Point beach. Ten beach profile stations were marked at regular intervals along the beach (Fig. 1), and profiles were made in June and December, 1990, and at selected stations in January, 1992. The beach profiles were used to construct general topographic maps of the beach for each time of measurement and to draw an isopach map showing the net erosion and deposition of sediments over the six-month period, June to December, 1990.

Forty-nine beach sediment samples were collected from along the profiles. These sediment samples were seived so that contour maps of sediment distribution could be constructed using the four Folk and Ward (1957) graphical statistical parameters: mean grain size, sorting, skewness, and kurtosis. Further details regarding study of the sediment samples are given later in this paper.

THE GEOLOGIC SETTING

The Sandy Point Beach lies along the southwestern corner of San Salvador Island. The beach

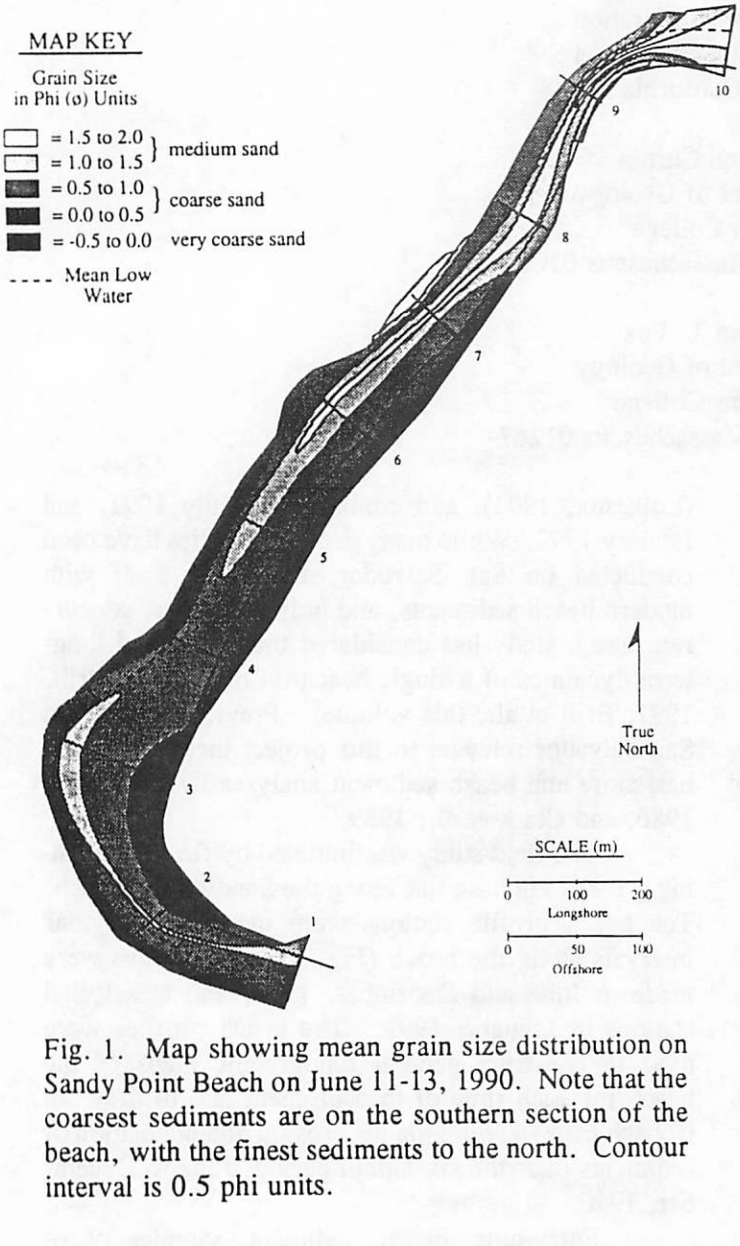


Fig. 1. Map showing mean grain size distribution on Sandy Point Beach on June 11-13, 1990. Note that the coarsest sediments are on the southern section of the beach, with the finest sediments to the north. Contour interval is 0.5 phi units.

study area begins on the west side of a southward-facing rock outcrop about 300 m east of the point of Sandy Point and continues around the point and northward, ending at cliffs of Pleistocene rock that form the northeast side of Grotto Bay. Almost the entire length of beach is backed by carbonate sand dunes, and the beach itself ranges in width from 20 to 100 m.

What makes this site particularly interesting is that the beach bends around Sandy Point and receives high energy waves along its southern exposure and generally low energy forces along its leeward, western side, particularly under fairweather (spring-summer) conditions. The predominant winds are easterly to southeasterly trades, with storms (excluding hurricans) most frequently coming from the north or northwest. During northwest storm conditions, such as those observed on June 15 and 16, 1990, the high energy forces are focused on the western side of the Sandy Point Beach, and generally calm (leeward) conditions prevail on the southern part of the beach.

SEDIMENTS OF THE SANDY POINT BEACH

The carbonate, skeletal sands of Sandy Point Beach range in grain size from fine to very coarse. Individual grains are predominantly off-white in color and very highly polished. Using the grain images of Powers (1953) for estimating the roundness of grains, the Sandy Point sediments are sub-angular to sub-rounded with high sphericity. Many grains have been cemented to neighboring grains to form grapestones. This cementation and subsequent polishing plus the polishing of generally finer individual grains makes recognition of the composition of individual grain types very difficult. Nonetheless, fragments of the green alga, *Halimeda*, and foram, coral, and mollusc fragments were identified as common constituents.

During June, 1990, forty-nine samples of beach sediments were collected for sieving (Loizeaux, 1991). Five samples were taken along nine profiles, with four samples only from profile one. The first sample (A) was taken at the middle of the backbeach, between the berm crest and the base of the primary dune. The next three samples (B, C, and D), were taken at 1/6, 3/6, and 5/6 the distance between the berm crest and the plunge step. The final sample, (E), was taken at the end of the profile at a water depth of approximately 1.5 m. At profile station 1 the offshore topography was dominated by large slabs of rock, with no sandy sediment available, so only four samples were collected along this line. All samples were taken at the surface.

The samples then were dried and sieved through a set of U.S. Standard wire-mesh sieves on a ROTAP vibrating machine at Williams College. The weight percents of each subsample were entered in the IBM ProbSpline (Middleton, 1990) and PC Sieve (Fox, 1991) computer programs that calculated a cumulative curve against phi probability. These programs also calculated the Folk and Ward (1957) four graphical statistical parameters: mean grain size, standard deviation, skewness, and kurtosis. These sediment samples displayed a high degree of variability for all four statistical parameters (Loizeaux, 1991). Only mean grain size and standard deviation (sorting) will be discussed here, as they reveal the most about the sediment migration models to be developed in this paper.

Mean Grain Size

The mean grain size of the Sandy Point beach sediments ranged from 2.29 ø to - 0.15 ø (0.22 mm to 1.12 mm). Using the Wentworth size classification scheme, these values correspond to fine to very coarse sand. The vast majority of samples (88%) were in the medium and coarse sand categories. A contour map of mean grain size for Sandy Point Beach was constructed (Fig. 1), and it showed that mean grain size varies considerably along the 2 km of this beach. The coarsest sediments are located on the southern part of the beach, between stations 4 and 5. As one moves north or south along the beach, finer sediments are encountered, with the finest sediments located between stations 9 and 10 at Grotto Bay.

Mean grain-size changes such as these can be good indicators of longshore sediment transport direction. A change in mean grain size from coarser to finer usually is indicative of the primary direction of sediment transport. As the finer grains are winnowed out of a higher energy environment by the wave swash, they are transported by longshore currents to be deposited in areas of lower energy (Chappell, 1967). The contour map, as it was drawn for June 11-13, 1990, suggests that the prevailing direction of sediment transport at that time was northward along Sandy Point Beach. The coarse sands of - 0.50 ø to 0.50 ø on the southern half of the beach gradually shift to medium sands of 1.0 ø to 2.0 ø on its northern half.

Standard Deviation (Sorting)

As with mean grain size, the beach sand samples displayed a wide range of sorting. Standard deviation values ranged from 0.88 ø to 0.29 ø on Sandy Point Beach. The corresponding verbal terms for these values are moderately to very well sorted. A contour map of sediment sorting was produced for Sandy Point Beach for June 11-13, 1990 (Fig. 2). The best sorting is found in a swath including stations 4, 5, and 6 and in a narrow band between stations 9 and 10. The southern half of the beach, between stations 1 and 6, is predominantly well sorted. The northern parts of Sandy Point Beach, from station 7 to 10, display a broader range of sorting.

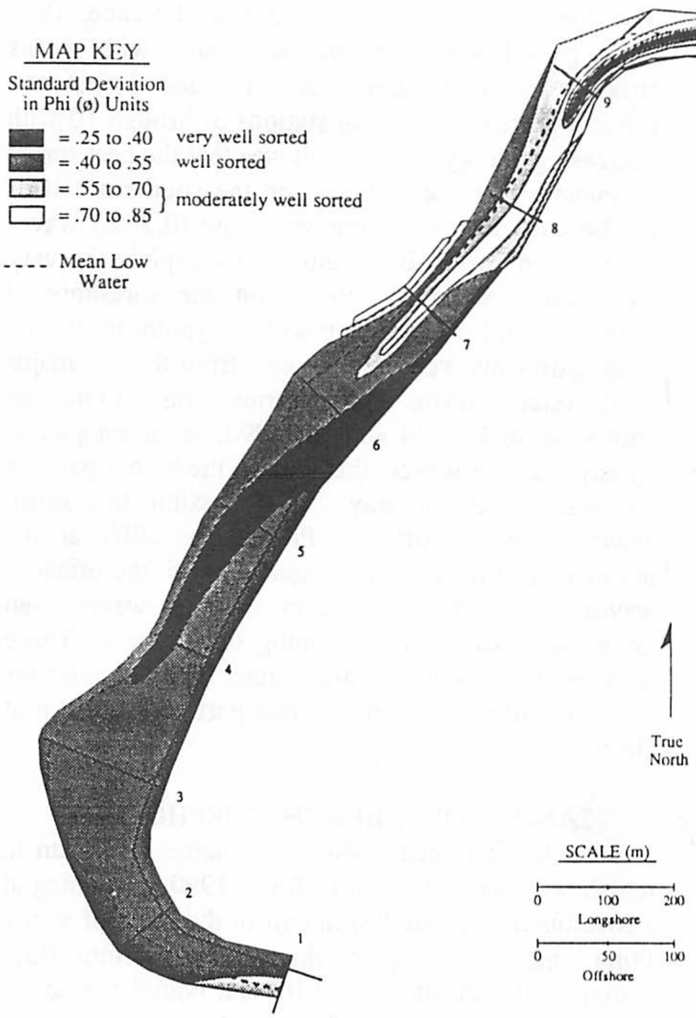


Fig. 2. Map showing the sorting of sediments on Sandy Point Beach on June 11-13, 1990. Note that the best sorting is found on the southern half of the beach and that the poorest sorting occurs on the northern half. Contour interval is 0.15 phi units.

One use of sorting as a statistical parameter is to assess relative energy environments on a beach. Samples with better sorting can be interpreted as being in the region with greatest energy and degree of sediment transport. Given this, the sieving results point to the conclusions that the region of greatest environmental energy is on the southern half of the beach and also up on the foreshore between stations 9 and 10.

Seemingly there is only partial agreement here with observations of waves and currents made in the field. The dominant wave direction during the June, 1990 study period was from the southeast, with waves striking the beach along stations 1 and 2 first and refracting around to strike stations 3 through 10 with decreasing energy. The result was that the best sorted sediments were concentrated on the southern half of the beach. However, the very low (0.2 m) waves observed in Grotto Bay cannot fully explain the very well sorted sediments found on the foreshore at stations 9 and 10. One possible hypothesis is that these sediments were lag deposits from the last major northwesterly storm. These storms, similar to the one witnessed on June 14 and 15, 1990, are accompanied by large, 2-3 m waves, that swamp the higher parts of the beach at Grotto Bay. It is possible that storm waves reflecting off the Pleistocene cliffs at the northeast end of the beach interfere with the offshore waves, and combine to form standing waves even larger than any single, incoming storm wave. These high energy, storm conditions most likely account for the well-sorted sediments in this part of the beach at Grotto Bay.

SANDY POINT BEACH MORPHOLOGY

As described earlier, a baseline 1.925 km in length was laid out in early June, 1990, beginning at a rock outcrop about 300 m east of the point of Sandy Point and continuing northward into Grotto Bay, ending at the Pleistocene cliffs that bound the northeastern side of the bay. The baseline was measured using a 50 m tape and compass. Starting at 50 m, each station was marked with a stake at every 200 m interval. Ending at 1,850 m, this left 10 regularly spaced stations along the entire length of Sandy Point Beach. In June and December, 1990, the beach was profiled perpendicular to the baseline at each of the 10 stations; in January, 1992, it was again profiled at the four southern-most stations. The profiles were made using the stake and horizon method, and they extend from the base of the slope of the primary dune to a water depth of approximately 1.5 m. Individual profile station markers could not be surveyed to determine their heights, so sea level was used as a base level point. As the tidal stage varied at the time each profile was made, all sea-level positions later were corrected to the standard mean low water level.

Six beach profiles are illustrated in figures 3 and 4. Each profile represents a single station that was profiled two or three times, with the respective profile dates shown. Over the six month period from June to December, 1990, there were noticeable changes at all 10 stations. Stations 3, 5, 6, 7, 8, 9, and 10 suffered significant amounts of sediment erosion. Station 4 showed both erosion and deposition, and stations 1 and 2 experienced dramatic deposition. The erosion at the northern stations, 5 through 10, varied between 0 and 2 m in depth and extended as much as 40 m across the beach.

The southern area of the beach, between stations 1 and 4, changed even more noticeably than the beach along the northern stations during the study period. Figure 3 shows the profiles from stations 1, 2, and 3. The net deposition at station 2 in December, 1990 is almost 4 m thick over a length of 85 m; in January, 1992 the deposition was 3 m thick over a length of 130 m. The magnitude of erosion at station 3 was almost as great, with sediment loss of nearly 3 m over a length of 60 m by December, 1990.

These profiles were used to construct topographic maps of Sandy Point Beach in both June and December, 1990 (Fig. 5), and the southern part of the beach in January, 1992 (Fig. 6). A number of significant changes were documented and can be observed using the three maps shown on these two figures. The beach became narrower between stations 5 and 9 over the initial six-month period. This is most noticeable at station 9 where, in December, the sea had encroached nearly to the base of the Holocene rock outcrops along this section of the beach. In addition to the narrowing at the northern stations, there was a significant change in the position of the sand lobe that was off of station 3 in June. By December, 1990, the lobe had moved to the very southwesterly tip of the island, off of station 2 (Fig. 5). The lobe was again at this location in January, 1992 (Fig. 6), when a steep and deep ridge-runnel topography was in place.

The profiles were used to construct an isopach map showing net erosion and deposition over the initial six-month study period (Fig. 7). This map gives the best overall view of the changes to Sandy Point Beach, as opposed to the more localized views that the profiles provide. The Figure 7 map shows how the beach was generally split into two regions, a northern area of erosion and a southern area of deposition. Also, the large sand lobe observed off station 3 in June had moved by December, 1990. Using a digitizer, the approximate volume of sediment transported was calculated. During this six-month period, approximately 68,000 m^3 of sediment were eroded from the northern parts of Sandy Point Beach, with 37,000 m^3 of sediment deposited to the south. The net

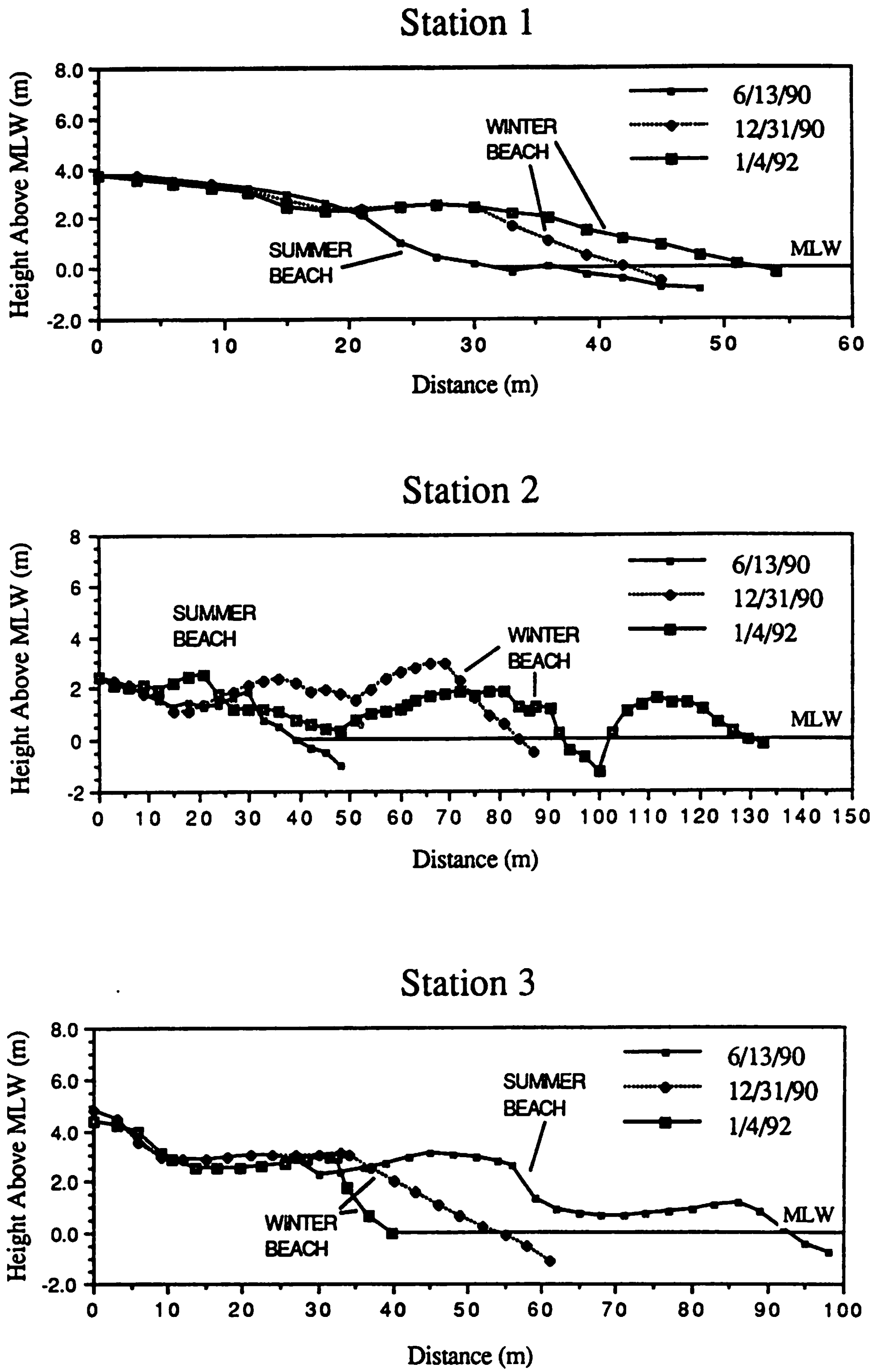
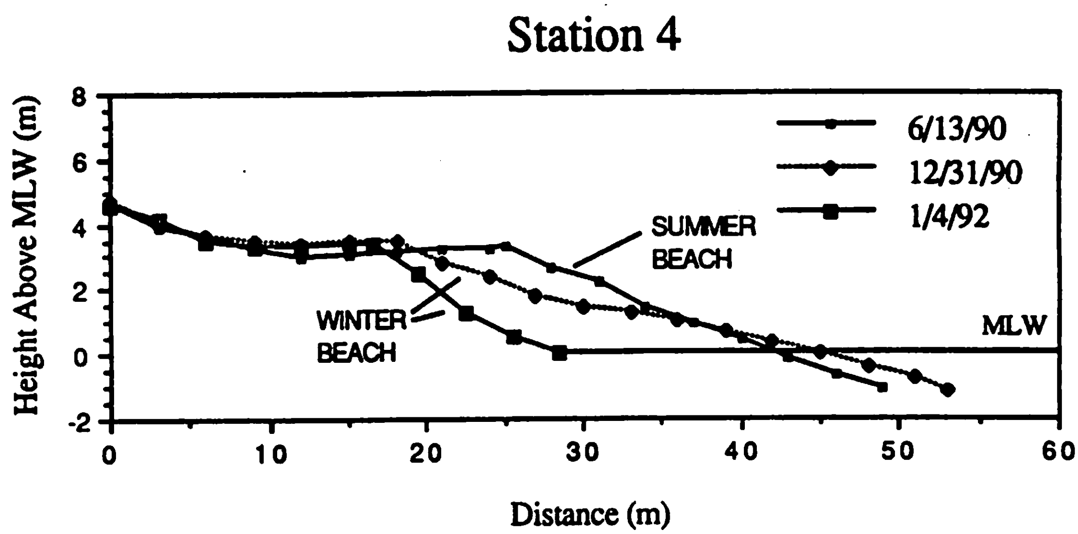
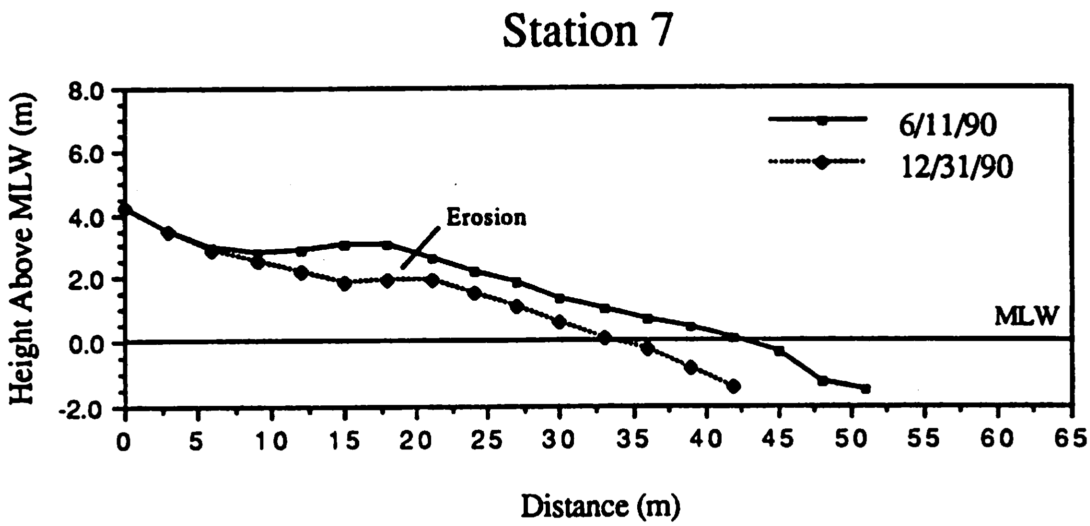


Fig. 3. Profiles of the Sandy Point Beach at stations 1, 2, and 3 in June and December, 1990 and January, 1992 showing erosional and depositional topographic changes.





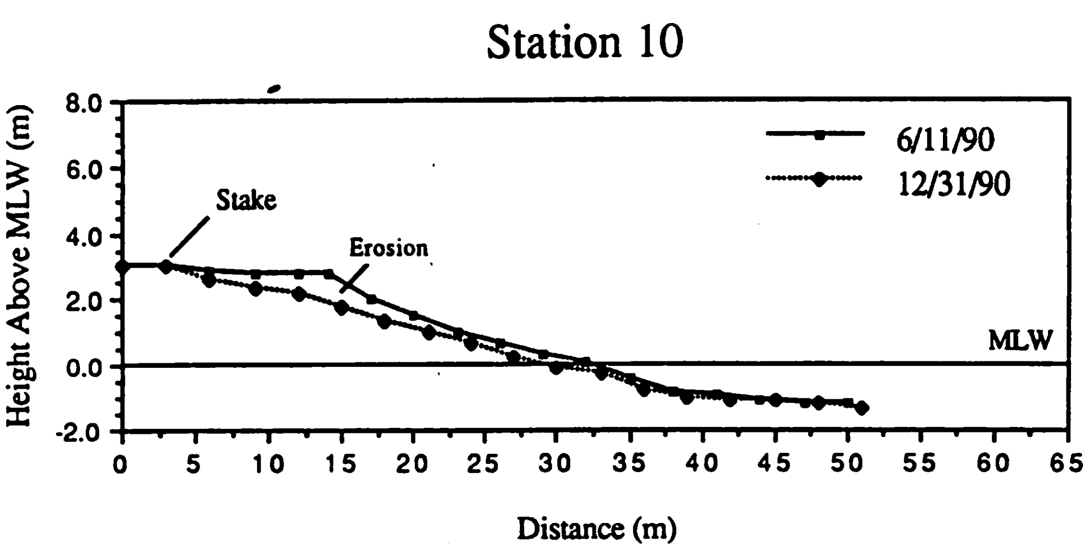


Fig. 4. Profiles of the Sandy Point Beach at stations 4, 7, and 10 in June and December, 1990 and January, 1992 showing erosional and depositional topographic changes.

erosion of 31,000 m^3 of sediment that is unaccounted for must have moved offshore or alongshore, out of the study area. This southerly net sediment transport between June and December, 1990 might seemingly be in opposition to the model of northerly sediment transportation postulated earlier based on the June wave observations, longshore current readings, and grain size parameters. The paradox is explained by phases of sediment transport as described below.

SEASONAL EROSIONAL AND DEPOSITIONAL CYCLES

The results of the sediment analyses and the beach topographic study along the Sandy Point Beach would appear to be in conflict with each other. The mean grain size analysis indicated that sediment had been moving in a northward direction from Sandy Point toward Grotto Bay immediately prior to and during the middle of June, 1990. The beach topographic study showed that over the six-month period between June and December, 1990 large amounts of sediment had been eroded from the northern sections of the beach, transported south along Sandy Point Beach, and deposited off of stations 1 and 2. These two, seemingly conflicting directional indicators together with the observations made on wind, waves, and weather give rise to a seasonal model for sediment transport along the Sandy Point Beach.

The Spring/Summer Beach

The measurements made in June, 1990, along with field observations from July, 1991, and the results of the sediment analyses done on samples collected in June, 1990, point to a cycle of sediment transport that we call the Spring/Summer phase. In this phase, the dominant trade-wind weather conditions prevail throughout the spring and summer months to form, by the early summer, a beach similar to the one studied in June, 1990. A number of factors including observed wave heights and longshore current readings, and mean grain size analysis, grain sorting, and sediment skewness support the concept of a Spring/Summer transport phase.

The wave and longshore current orientations recorded in June, 1990 support a northerly moving sediment transport direction. During this Spring/Summer phase, the largest waves hit the south coast and refract around the point of the island to continue northward. These waves create a longshore current that moves northward, carrying sand with it.

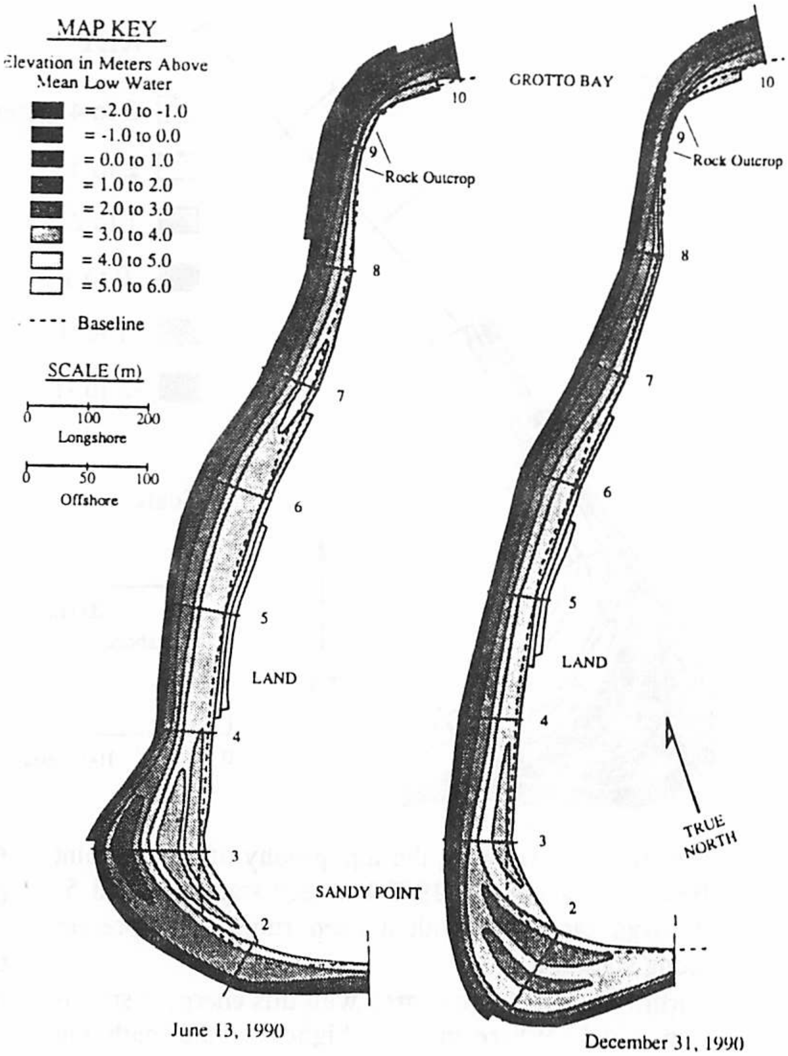


Fig. 5. Maps showing the topography of Sandy Point Beach in June (left) and December (right), 1990. Note the dramatic narrowing of the beach at the northern stations by the end of December, and the change in position of the sand lobe originally located at station 3 on the June beach. Contour interval is 1 m.

The finer sediments tend to build up on the northern section of the beach in the vicinity of Grotto Bay. Figure 8 presents a schematic diagram of this spring/summer beach phase.

The sediment analyses also provide evidence for a northerly moving sediment direction. The mean grain size analysis indicated that the coarsest sediments were located on the southern half of the beach and that the finer sediments occurred along the northern section along Grotto Bay (Fig. 1). The higher energy environment of the southern part of the beach causes the winnowing out of finer sediments and their transport

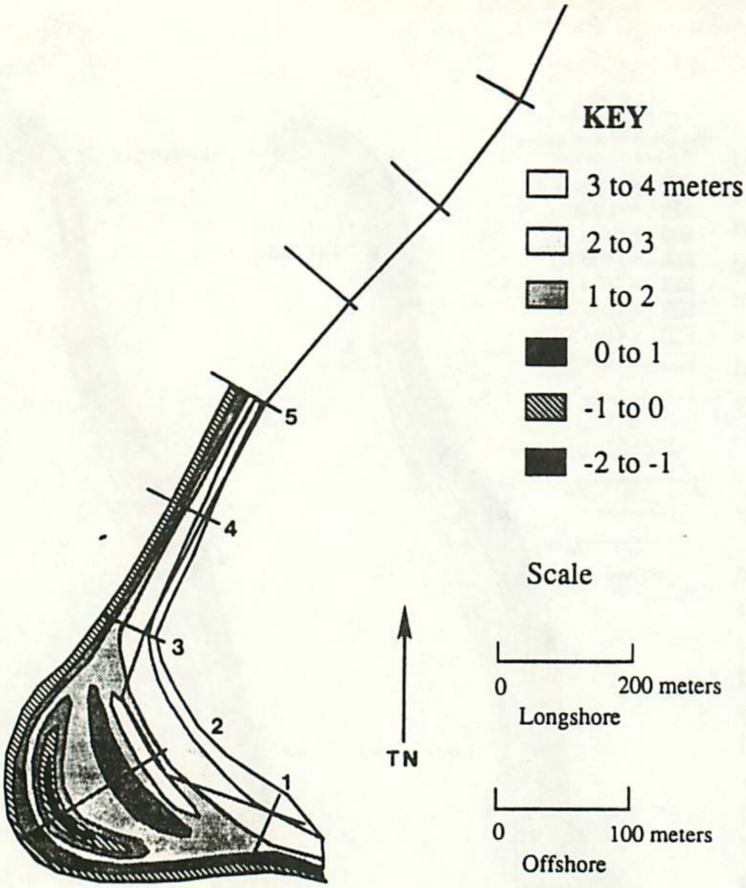


Fig. 6. Map showing the topography of Sandy Point Beach on January 4, 1992 between stations 1 and 5. A large sand lobe with a deep runnel was present along station 2.

north. Sorting results agree with this energy distribution model. Where energy is highest, to the south, the coarse sediment samples tended to have very good sorting, indicating that the waves and currents had removed the finer materials (Fig. 2). Skewness results, although not discussed in detail here, agreed as well, with the coarsest, or most negatively skewed samples located between stations 1 and 4 and the finer, more positively skewed samples located to the north (Loizeaux, 1991).

The sorting and skewness results, however, presented a seeming anomaly off of stations 9 and 10. Here, not only well sorted, but coarse, negatively skewed sand samples occurred. As previously mentioned, our explanation is that these coarser sediments are storm lag deposits from a recent, northwesterly storm. It is also likely that the sediments of the backbeach are storm overwash deposits. This would explain why they are relatively coarser, better sorted, and more negatively skewed than the sediments of the middle foreshore that were deposited under more normal, non-storm conditions. During these normal conditions, the tidal range and wave heights are low and do not affect the backbeach and the sand deposits there. Davis (1985) theorized that low energy regimes provide an overall constructional character to a beach. He attributed this to the net landward movement of sediments by waves with low steepness and low wave height. This general model agrees with our observations from the Sandy Point Beach. The June, 1990 topography, compared to that of December (Fig. 5), indicated that large volumes of sediment make the beach broader in the northern section and narrower in the southern section during the Spring/Summer phase. Presumably, an extended period of calm, normal, conditions would allow for buildup along the northern section of the beach with the typical longshore current. However, the rate and amount of sediment transported under these conditions is likely to be much less than that of storm conditions.

The Fall/Winter Beach

The most typical storm direction during the fall and winter season is from the north or northwest (Clark et al., 1989). The notable exception would be late summer-fall hurricanes that normally come from the east or southeast (Anonymous, 1976). Although many features of a Bahamian island's topography might be attributable, in part, to the effects of hurricanes (Sealey, 1985), their frequency (115 per 1,000 yrs.) is such that this relatively short-term study cannot address their effects. It is the much more frequent, northwesterly storms that we think are responsible for the topography of Sandy Point Beach as observed in December, 1990 and January, 1992. This topography represents what we term the Fall/Winter phase.

Our qualitative wave and longshore current estimates made during a northwestern storm of June 14 and 15, 1990 suggest a model where the net sediment transport direction is to the south. This is schematically diagramed in Figure 9. Large waves come out of the north or northwest, move directly into Grotto Bay and strike the length of Sandy Point Beach obliquely. These waves are responsible for forming a southerly longshore current much more powerful that the one observed moving in the opposite direction under normal energy conditions. The higher frequency of northwestern storms in the fall and winter explains the large amounts of sediment found off stations 1 and 2 in December, 1990, and again in January, 1992.

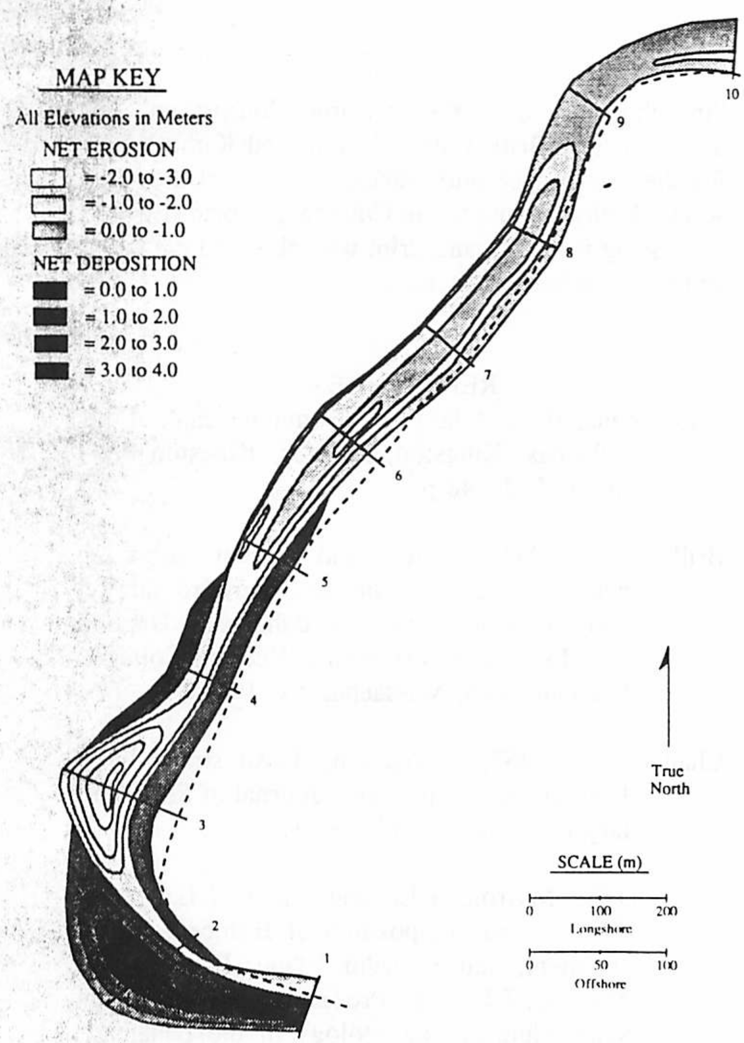


Fig. 7. Map showing net sediment erosion and deposition over the six month period from June to December, 1990. Note the erosion from the northern sections of the beach and the significant deposition in the area of stations 1 and 2 to the south. Contour interval is 1 m.

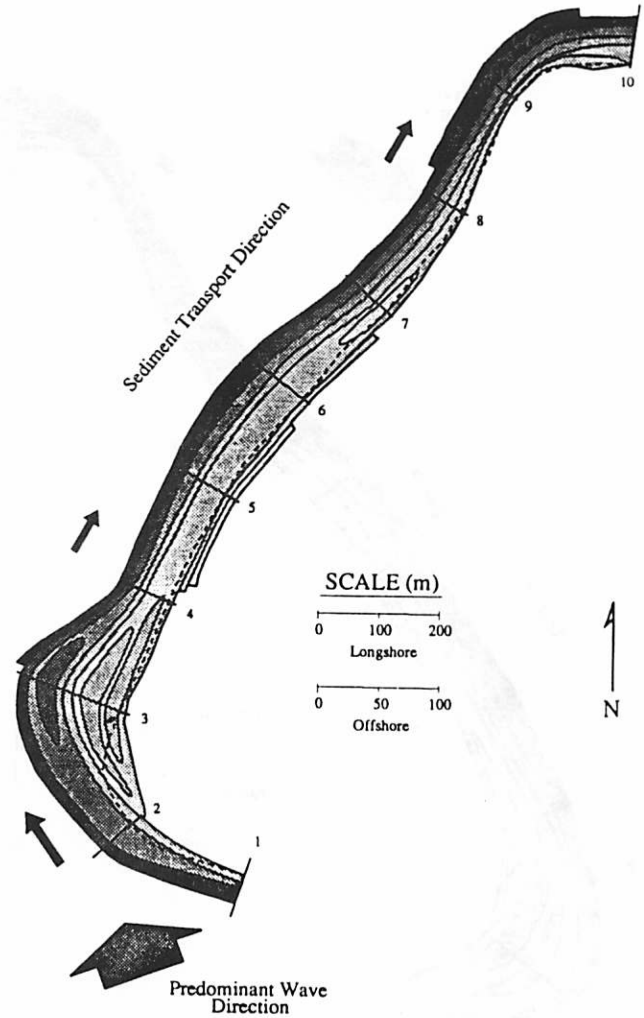


Fig. 8. Schematic diagram to illustrate the Spring/Summer sediment transport phase. During trade-wind conditions, the highest wave energy is focused on the southern exposure of beach.

Without extended periods of trade wind conditions, the beach does not have time to "recover" fully during fall and the winter months. The "recovery" comes with the resumption of trade wind conditions and the development of the Spring/Summer phase.

CONCLUSIONS

The grain-size and profile data collected from the Sandy Point Beach between June, 1990 and January, 1992 have documented much about the characteristics and dynamics of sediment transport on this beach. Two phases of sediment transport are indicated, a Spring/Summer phase of northerly sediment transport under the influence of waves generated by the prevailing easterly trade winds, and a Fall/Winter phase with a southern direction of transport from northwesterly storms. More specific conclusions are as follows:

1. The carbonate, skeletal sands of the Sandy Point Beach range in size from fine to very coarse grains. All grains are highly polished; the coaser grains are predominantly in the form of grapestones. The sands are moderately to very well sorted.

2. Analysis of the mean grain size and standard deviation (sorting) distributions indicated a northerly direction of sediment transport. This is the Spring/Summer phase of sediment transport, under the influence of waves generated by the prevailing easterly trade winds. This also is probably the "normal" direction of sediment transport under general, non-storm conditions.

3. Comparison of beach profiles taken at three intervals over an eighteen-month period revealed the existence of a strong southerly direction of transport as well. This transport results from higher than normal

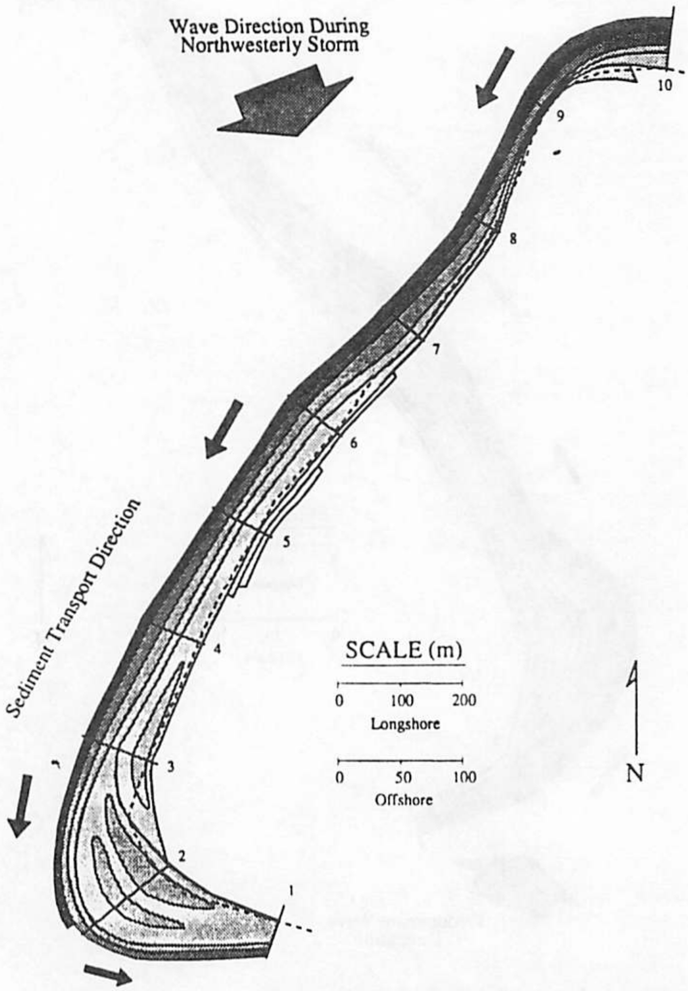


Fig. 9. Schematic diagram showing the Fall/Winter sediment transport phase. The frequent north-northwesterly storms that occur during late fall and winter move sediment south along the beach. Without extended periods of calmer, trade-wind conditions, the beach does not "recover" until late spring and summer.

energy conditions generated by northwesterly storms. This transport phase is dominant in the fall/winter months, when large quantities of sand can be moved rapidly to the southern section of the beach. The two-directional (N-S) sediment transport system operative along the Sandy Point Beach makes it one of most dynamic, rapidly changing beaches on the San Salvador Island coast.

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