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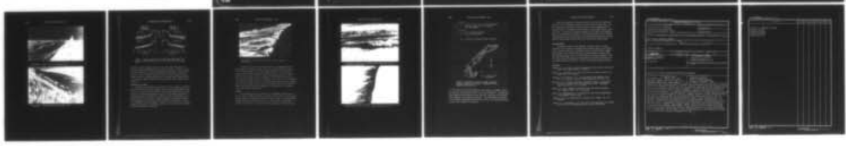

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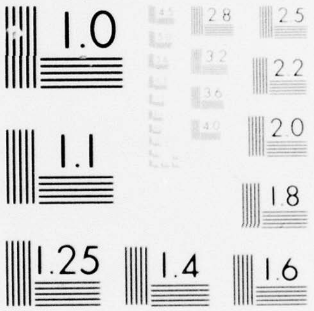

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PROCESS AND MORPHOLOGY CHARACTERISTICS OF TWO BARRIER BEACHES IN THE MAGDALEN ISLANDS, GULF OF ST. LAWRENCE, CANADA

by

E. H. Owens

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CHAPTER 115

PROCESS AND MORPHOLOGY CHARACTERISTICS OF TWO BARRIER BEACHES IN THE MAGDALEN ISLANDS, GULF OF ST. LAWRENCE, CANADA

by

E. H. Owens

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Baton Rouge, Louisiana 70803

ABSTRACT

Detailed field investigations of barrier beach morphology and processes at adjacent sites in the Magdalen Islands, Gulf of St. Lawrence, show that the two beaches are in distinctly different morphodynamic environments. The differences are expressed in terms of wave energy levels, sediment dispersal patterns, and nearshore, littoral, and dune geomorphology. The exposed west-facing coast has a steeper offshore gradient, is a zone of sediment bypassing, and has a complex sequence of three nearshore bars. Wave energy levels are lower on the sheltered east coast, and this is a zone of sediment redistribution and deposition with a single, linear nearshore bar. The different morphological characteristics of the two barriers are attributed to the spatial variation in energy levels and to the differences in offshore gradients on the two coasts. Computed wave energy values, derived from data monitored during two study periods (August and November, 1974), indicate that the mean wave energy levels were greater on the west coast as compared to the east coast by factors of 2.25 in summer and 2.95 in winter. This is due primarily to the dominance of winds out of the westerly quadrant throughout the year.

INTRODUCTION

The Magdalen Islands consist of a series of barrier beaches that are oriented northeast-southwest to connect small bedrock outcrops on the shallow central shelf of the southern Gulf of St. Lawrence (Owens, 1975) (Figure 1). This is a microtidal environment (mean tidal range less than 1.0 m) and, as the Gulf is an enclosed sea, the wave climate is dominated by locally-generated wind waves. Winds are dominantly from between southwest and northwest throughout the year, with a higher frequency of storm winds in winter months (Table 1). Limiting factors for wave action on the beach are maximum fetch distances on the order of 300 km and the presence of sea or beach-fast ice for periods up to four months each winter. Littoral processes are dominated by wind waves associated with the west to east passage of low-pressure systems across Atlantic Canada (Table 2). On the west coast of the Magdalen Islands the shoreline is exposed to the dominant and prevailing winds out of the northwest. Maximum wave and breaker height values on the west beach occur at times of maximum wind velocities, independent of wind direction. On the east-facing coast wave characteristics are closely associated with the onshore wind component (Owens, 1977).

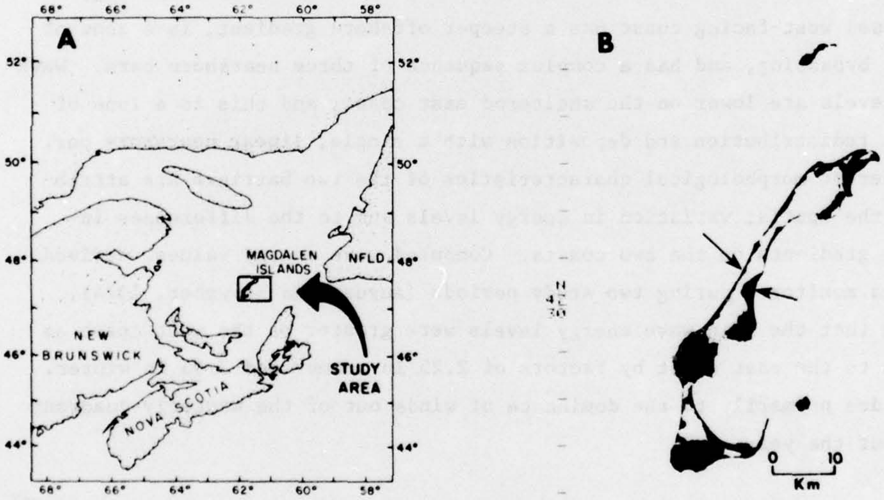


Figure 1. Magdalen Islands study area: A. Location. B. Study sites on the central tombolo.

Table 1. Wind Data, Magdalen Islands (1933-1972)

	Mean Wind Velocity (km/h)	Mean Direction	Mean Hours/Month with Given Wind Velocities		
			88-101 km/h	102-120 km/h	>120 km/h
Jan.	47.2	NW	13.4	2.0	0.1
Feb.	41.4	NW	7.2	1.8	0.4
March	40.6	NW	6.2	0.4	0.4
April	36.2	NW	1.8	0.3	--
May	35.2	NW	0.4	--	--
June	33.3	NW	0.2	--	--
July	30.6	SW	--	--	--
Aug.	30.4	SW	0.7	--	--
Sept.	35.7	NW	1.7	0.4	--
Oct.	41.0	NW	5.0	0.7	--
Nov.	41.7	NW	6.5	1.4	0.7
Dec.	45.7	NW	9.0	2.2	0.2

Table 2. Storm Duration and Frequency, Magdalen Islands

A. Number of Storms with Winds >90 km/h and >115 km/h by Quadrant Over a 40-Year Period

	>90 km/h	Duration >3 hours	Duration >6 hours	>115 km/h	Duration >3 hours
NW-NNE	256	68	37	15	3
NE-ESE	62	12	3	--	--
SE-SSW	124	15	5	2	--
SW-WNW	120	15	9	8	1

B. Annual Frequency of Storm by Quadrant

	>90 km/h	Duration >3 hours	Duration >6 hours	>115 km/h	Duration >3 hours
NW-NNE	6.4/yr	1.7/yr	0.9/yr	2 in 5 yr	1 in 13 yr
NE-ESE	1.5/yr	1 in 3 yr	1 in 13 yr		--
SE-SSW	3.1/yr	2 in 5 yr	1 in 8 yr	1 in 20 yr	--
SW-WNW	3.0/yr	2 in 5 yr	1 in 4 yr	1 in 5 yr	1 in 40 yr

Mean and maximum wave height values are greater on the west coast in all seasons due to the prevailing onshore winds. A distinct difference in wave energy levels exists between the two study sites (Figure 2). Comparison of computed wave energy values (Table 3), derived from time-series data monitored during two study periods (August and November, 1974), shows that the mean values are greater on the west coast by factors of 2.25 and 2.95 for the summer and winter phases of the study. The same comparison for the computed longshore sediment transport rates (Table 4) shows that the combined hourly rates are greater on the west coast by 2.7 and 2.0 for the summer and winter study periods. The estimated annual gross volume of longshore sediment transport is approximately four times greater on the west-facing barrier.

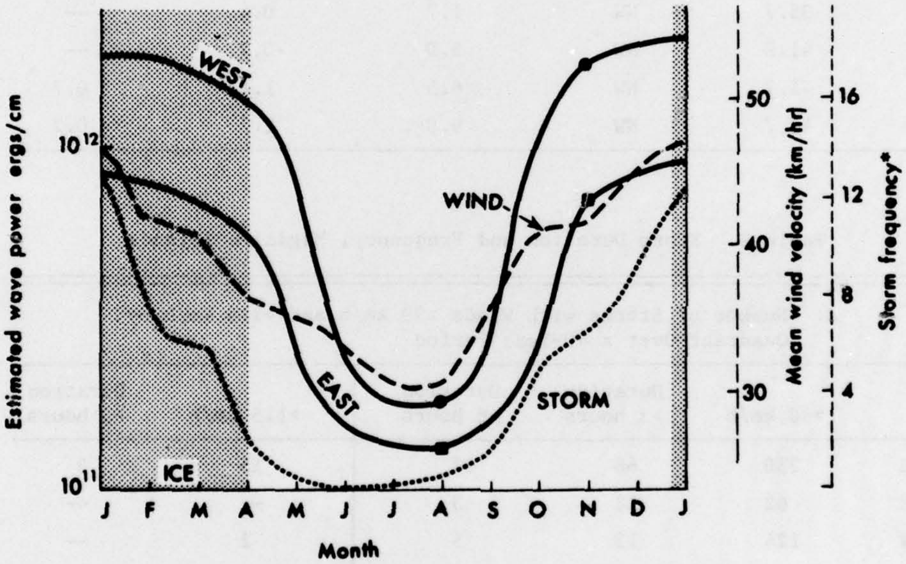


Figure 2. Seasonal variations in (1) estimated wave energy on the east and west barriers, (2) mean monthly wind velocity, and (3) storm frequency. The period of sea-ice cover or beach-fast ice is indicated by the shaded area. Wave energy values are extrapolated. Storm frequency (*) is the number of periods in each month when wind velocities exceed 55 km/h, based on data over a 40-year period.

Table 3. Computed Wave Energy Values (ergs/cm)

		Mean	Minimum	Maximum
Summer	West	2.52×10^{11}	2.12×10^{9}	1.65×10^{13}
	East	1.12×10^{11}	2.12×10^{9}	1.10×10^{13}
Winter	West	2.51×10^{12}	1.68×10^{11}	7.38×10^{13}
	East	8.51×10^{11}	3.04×10^{10}	5.89×10^{13}

Table 4. Summary of Computed Longshore Sediment Transport Rates

		West Coast	East Coast
Average Hourly Rate (m^3/h)	Summer	149 to N	53 to N
		95 to S	39 to S
	Winter	631 to N	265 to N
		519 to S	315 to S
Net Daily Rate (m^3/day)	Summer	428 to N	201 to N
	Winter	1,261 to N	962 to S
Estimated Annual (m^3/yr)	Gross	2,059,030	550,943
	Net	233,931 to N	104,112 to S

Owens (1977) has shown that in addition to this spatial variation there is also a distinct temporal variation in energy levels between the two sites that is reflected in littoral zone morphology. On the west coast there is a seasonal variation in wave energy levels that produces a "summer-winter" beach cycle. On the sheltered east coast variations in energy levels due to the passage of low-pressure systems across the region are more important than the seasonal variations. This produces beach cycles of erosion during storms and deposition during the post-storm recovery period (Table 5).

Table 5. Characteristic Differences between the Coastal Environments of the East and West Barriers--Magdalen Islands

	West	East
Wave energy	a. High energy environment b. Marked seasonal variation in wave energy levels	a. Moderate energy environment b. Large short-term variations due to storm-wave activity
Littoral zone morphology	a. "Summer-winter" beach cycle b. Relatively stable morphology in plan and profile	a. Storm/post-storm beach cycle b. Large short-term variations in morphology
Offshore Slope	0°10'	0°05'
Nearshore Slope	0°33'	0°53'

OFFSHORE ZONE

On the shallow shelf adjacent to the west coast of the Magdalen Islands, sediment is being transported landward by present-day processes (Owens, 1975). This is an area of coarse and medium sands (Table 6) and is a non-depositional sedimentary environment, with local reworking and the formation of lag deposits (Loring and Nota, 1973). Sediment that is transported toward the Islands is moved rapidly alongshore in shallow water toward and around the extremities of the barriers. The shelf adjacent to the east coast is sheltered from waves out of the west and is a depositional area of fine-grained sediments (Table 7) (Loring and Nota, 1973).

The nature of the sedimentary environments on the Magdalen Shelf is controlled in part by differences in the wave climate to the west and to the east of the islands that result from the dominance of wind-generated waves out of the west. In the zone of sediment reworking and transportation on the shelf to the west of the Islands the sandstone bedrock is overlain by a thin, discontinuous layer of sand and gravel. In the depositional area to the east of the Islands the bedrock is buried by a continuous cover of well-sorted

Table 6. Sedimentary Environments--Magdalen Islands

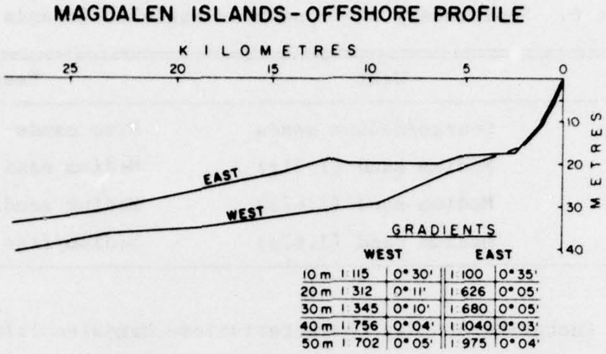
	West	East
Offshore	Coarse/medium sands	Fine sands
Nearshore (<5 m)	Medium sand (1.31ϕ)	Medium sand (1.81ϕ)
Beach	Medium sand (1.67ϕ)	Medium sand (1.87ϕ)
Dunes	Medium sand (1.67ϕ)	Medium/fine sand (1.95ϕ)

Table 7. Energy-Morphology Characteristics--Magdalen Islands

		West	East
Sediment dispersal	Offshore	Toward east	Zone of deposition
	Nearshore	Rapid longshore movement	Zone at redistribution and deposition
Subaqueous profile		Relatively steep (1:300)	Relatively flat (1:625)
Frictional attenuation of waves		Low	High
Amount of energy reaching shoreline		High	Low

sands (Loring and Nota, 1973). The gradients of the subaqueous slope off the west- and east-facing barriers are therefore partially controlled by the sediment dispersal pattern that results from the local wave climate.

Wright and Coleman (1972) note that nearshore wave power is a function of the subaqueous slope, due to the effects of frictional attenuation, and that as water depth decreases frictional attenuation rates increase. The offshore profiles adjacent to the two barriers are very different (Figure 3), particularly between the 15-m and 40-m depth contours. The broad, shallow shelf off the east coast has an average gradient of 0°05' (1:626) from the shoreline to the 20-m contour, approximately half the gradient of the shelf off the west coast (0°11', 1:312). Wave periods are usually less than



	WEST		EAST	
10 m	1:115	0° 30'	1:100	0° 35'
20 m	1:312	0° 11'	1:626	0° 05'
30 m	1:345	0° 10'	1:680	0° 05'
40 m	1:756	0° 04'	1:1040	0° 03'
50 m	1:702	0° 05'	1:975	0° 04'

Figure 3. Offshore profiles and gradients--taken on lines perpendicular to the shoreline at the two study sites.

8 seconds in the Gulf, so that although some longer period waves would feel bottom in water depths up to 50 m, the frictional attenuation rates would probably be highest in depths between 30 m and 10 m.

Due to the shallower depths on the east coast the loss of energy by frictional attenuation is much greater than on the west coast. In addition, as the dominant and prevailing winds are out of the west, and locally-generated waves dominate the wave climate, the east coast is a protected environment in which wave heights are lower than on the west-facing barrier (Owens, 1977). The net effect is that (1) more energy is available on the western barriers (Table 3) and (2) a higher proportion of that energy reaches the nearshore zone as compared to the east-facing barrier.

NEARSHORE ZONE

The effects of the difference in the wave energy levels on the two coasts are clearly reflected in the nearshore zones. Surveys on the west study site show a large crescentic bar system that shoals to 5-6 m at 800 m from the beach, a smaller middle crescentic bar, and an intermittent inner bar (Figure 4). Comparison of field surveys in 1974-75 with aerial photographs taken in 1970 indicates that the plan form of the outer bar appears to be constant through time. Small longshore movements of the outer crescentic bar system result in occasional overlapping of the bars in the vicinity

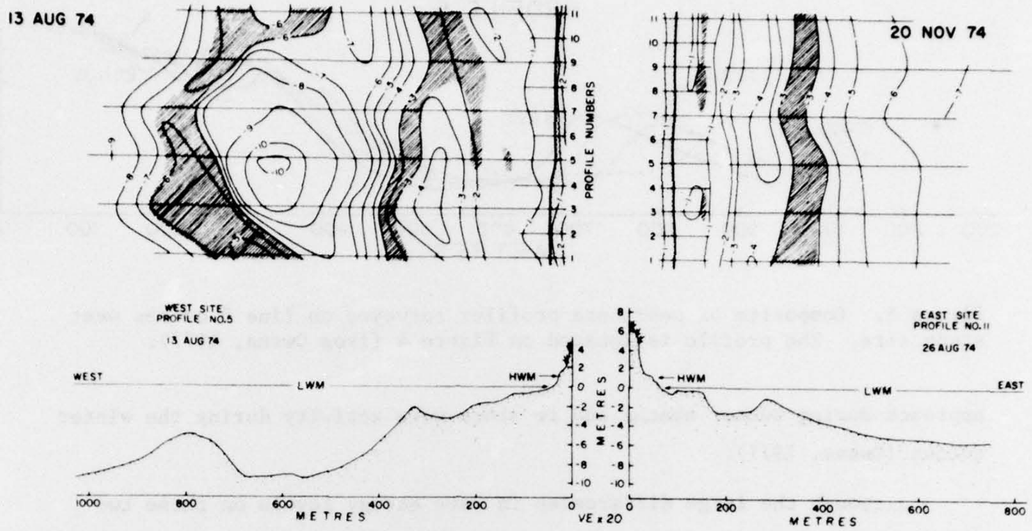


Figure 4. Nearshore profiles and morphology at the west and east coast study sites. The nearshore profiles are spaced at 100-m intervals and shaded areas on the maps indicate the location of subaqueous bars.

of the horns of the crescents. Also, it was found that the apex of the outer bar oscillated perpendicular to the shoreline between 700 and 900 m from the beach (Figure 5). These variations resulted in modification of the crescentic bar form but surveys showed that the basic location and shape of the outer bar did not change over a 9-month period. More variation was observed in the plan form of the two inner bar systems, particularly following periods of storm-generated waves.

By contrast the east-facing barrier is characterized by a single asymmetrical linear nearshore bar that shoals to 1.5-2.5 m at 250 m from the beach (Figure 4). The trough depth on the landward side of the bar varied between 3 and 5 m. Migratory bars were also recorded inshore on the shallow low-tide terrace adjacent to the beach. Although the nearshore bar had a low amplitude rhythmic plan shape following storm-wave activity, the basic linear form of the bar did not change significantly over the 9-month period of the surveys. The plan form of the bars on the low-tide terrace varied considerably, and this has been related to differences in the direction of wave

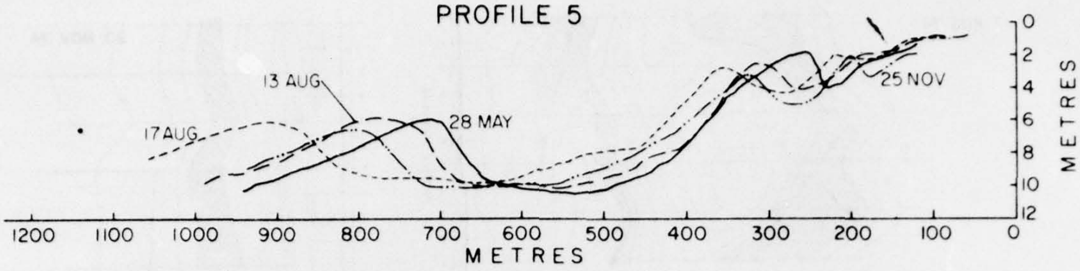


Figure 5. Composite of nearshore profiles surveyed on line 5 on the west study site. The profile is located on Figure 4 (from Owens, 1977).

approach during summer months and to storm-wave activity during the winter season (Owens, 1977).

Although the large differences in wave energy levels on these two barriers clearly affect the character of the nearshore zone, the actual variations in the size and the morphology of the nearshore bar systems could be explained in several ways. If it is assumed that breaking waves control bar formation, then the fact that the bars on the western barrier are farther offshore, in deeper water, and larger than the bar on the east coast would be due simply to higher wave heights on the west coast. But, as the two sets differ so radically in plan form it is difficult to accept that bar formation could result from a simple variation in wave height between the two coasts. On the other hand, it is possible that the variation in the size and spacing of the bars, perpendicular to the shore, could be due to the effects of standing waves generated by the reflection of incident waves from the beach (Bowen and Inman, 1971; Suhayda, 1974). Bowen and Inman suggest that the alongshore plan form of crescentic bars results from the sediment dispersal patterns associated with the formation of edge waves in the surf zone. The absence of a well-defined crescentic bar on the eastern barrier probably results from the consistently oblique wave approach and high breaker angles that generate strong longshore currents, thus preventing the development of rhythmic morphology on the outer bar.

INTERTIDAL ZONE (BEACH)

Sediment size (Table 6) and tidal range are constant between the beaches of the two study sites, so that variability in beach morphology results from differences in wave energy levels or in nearshore topography modifying the incoming incident waves. The beaches of the western barrier are generally narrow (20-30 m) (Photograph 1) with a relatively steep beach-face slope (approximately 1:4) (Figure 6). These beaches are characterized by an overall lowering of beach elevation in winter months, due to increased levels of wave activity during this season. This produces a "summer-winter" beach cycle (Figure 7).

The beaches of the eastern barrier are wider (40-50 m) (Photograph 2) and have a flatter beach-face slope (approximately 1:8) (Figure 6). The dominance of storm-wave activity over seasonal variations in wave energy levels on this coast produces beach cycles that are related to erosion during storms and recovery during post-storm conditions. Although the beach elevation is lower in winter months, as compared to the summer (Figure 7), the short-term variability related to storm-wave activity is more significant (Owens, 1977).

The difference in slope of the beach face at the two sites is a reflection of the different effects of nearshore topography on breaking waves. Waves reaching the beach face on the west coast were predominantly plunging breakers, during both study periods, whereas those on the east coast were predominantly spilling breakers. This difference in breaker type results from the different gradients immediately seaward of the intertidal zone. Water depths and gradients are greater at the west study site (Figure 4) due primarily to the presence of a wide low-tide terrace on the east-facing barrier.

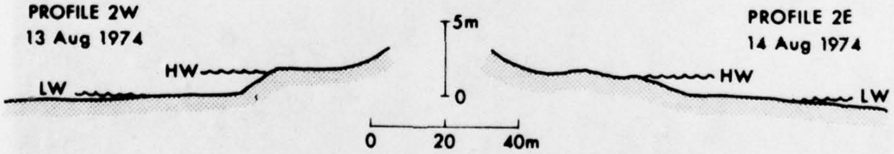
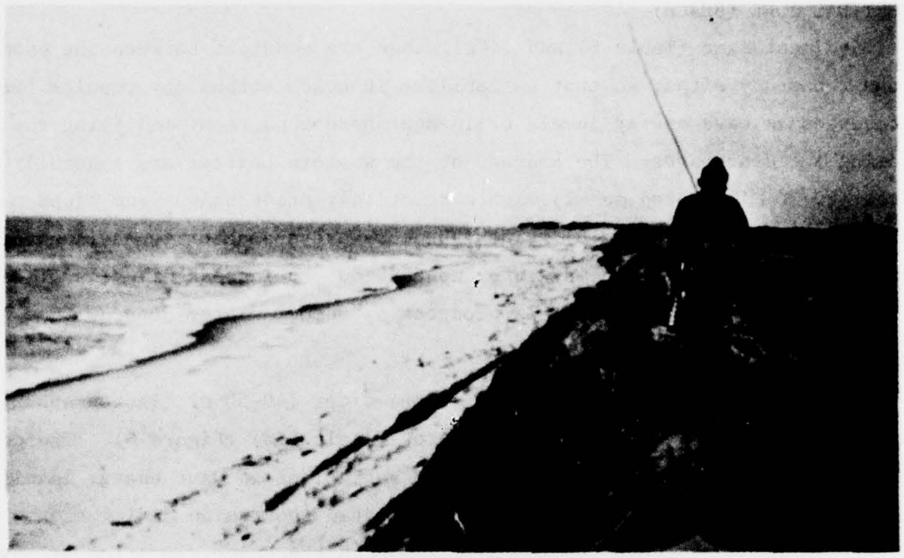


Figure 6. Representative beach profiles for the two study areas.



Photograph 1. West study site beach (May 1975).

Photograph 2. East study site beach (August 1974).

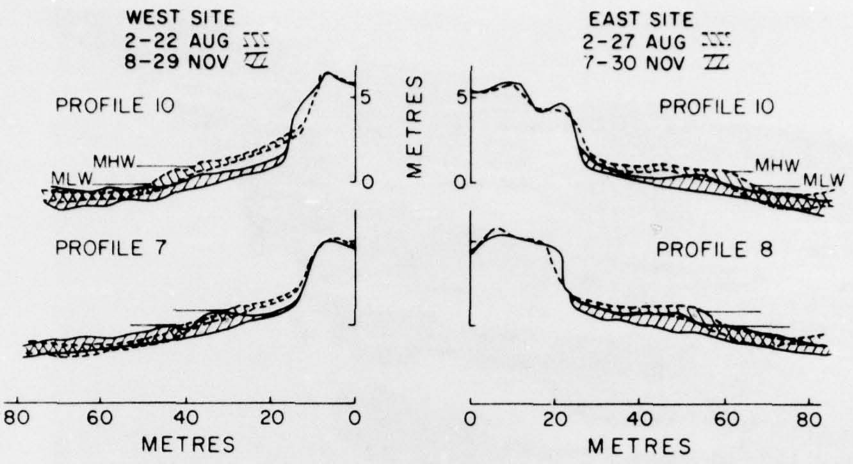


Figure 7. Sweep zone profiles for summer and winter beach profiles at selected locations for the two study sites (after Owens, 1977).

The berm crest was slightly higher on the western beach (Figure 6) as a result of higher wave heights on this coast that lead to a build-up of sand to greater elevations on the berm during high tide periods. Bascom (1954) pointed out that, although storm waves tend to erode the berm, they also create a berm at a greater elevation due to increased wave heights and that they may leave a high, narrow berm that will survive until a larger storm erodes it.

SUBAERIAL ZONE (DUNES)

The dunes on the western barrier are up to 15 m in height, and erosion during major storms produces irregular scarps in the backshore dunes (Photograph 3). During post-storm recovery a new foredune ridge develops adjacent to the beach, leaving an abandoned scarp that is subsequently modified by eolian processes. This pattern of irregular erosion in the backshore, followed by infilling to maintain a regular shoreline, has produced a complex dune topography. The concentration of wave energy at particular locations along the dune barrier is probably a reflection of the effects of the complex nearshore morphology on storm waves.

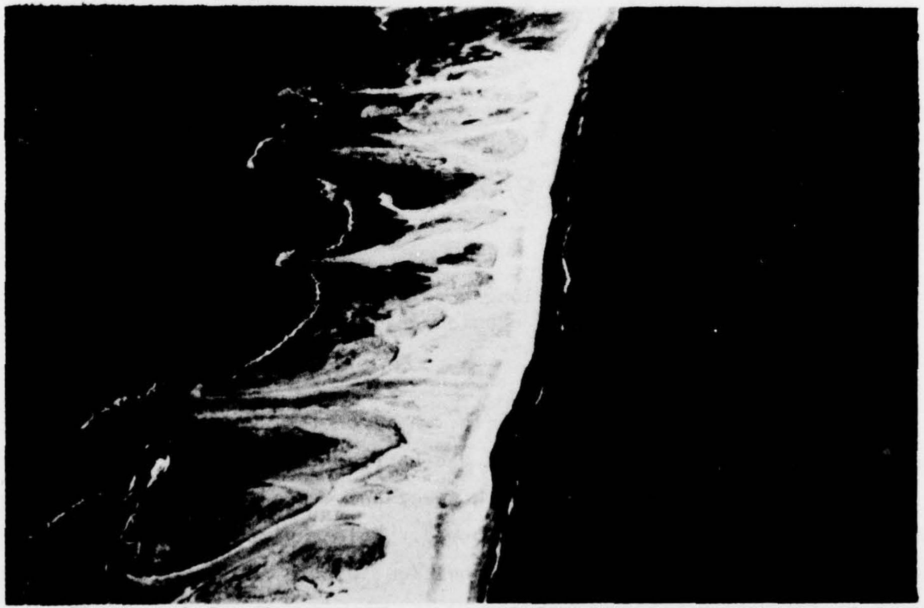
Photograph 3. Aerial view of dunes at the west study site (August 1974).

The dunes of the east study site are part of a progradational dune-ridge complex (Photograph 4) with a series of parallel ridges that reach 10 m in height adjacent to the beach (Owens and McCann, in preparation). Erosion during storms is relatively constant along this section of barrier, and there is no evidence that the ridges have been breached at any time. This dune-ridge complex is not characteristic of all the east-facing barriers of the Magdalen Islands (Figure 8). Elsewhere dune heights are rarely greater than 5 m and storm-wave erosion causes the development of washover channels that breach the dunes and the development of fan deposits on the lagoonal side of the barrier (Photograph 5).

SUMMARY

The high energy west-facing barriers of the Magdalen Islands are primarily a zone of sediment bypassing. Material that is fed into the nearshore-littoral system is transported rapidly alongshore toward the northeastern and southern extremities. The barriers are relatively stable, with washover deposits occurring only in the updrift sections adjacent to bedrock outcrops

Photograph 4. Aerial view of beach-ridge complex at the east study site (August 1974).



Photograph 5. Washover channels and fan deposits on the east-facing barrier to the north of the east study site (August 1974).

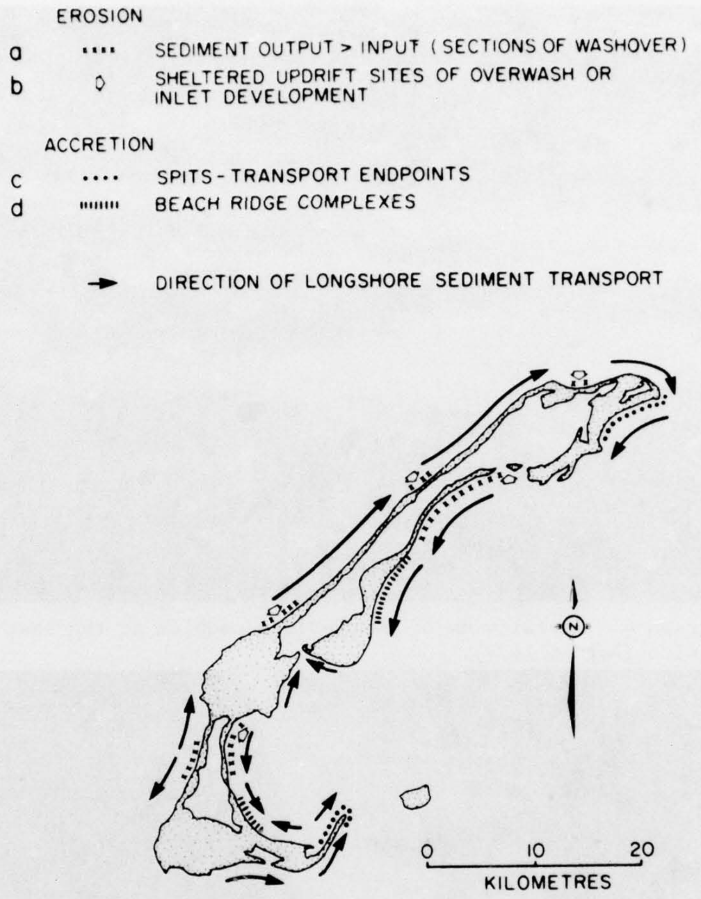


Figure 8. Generalized longshore sediment transport directions and areas of erosion or deposition on the Magdalen Islands barriers.

or, in the case of the southern tombolo, where there is a movement of sediment away from the central section of the barrier (Figure 8). The sheltered, lower energy eastern barriers are both lower and, except for the two beach-ridge complexes, are frequently overwashed. This environment is primarily one of sediment redistribution and deposition, with a net nearshore-littoral transport from northeast to southwest.

These basic mesoscale differences between the two barrier systems are reflected in the morphology and process characteristics of each coast. Spatial variations in offshore, nearshore, beach, and dune morphology can be directly related to the amounts and variability of wave energy levels on the two coasts. The pattern of sediment dispersal in the offshore and nearshore zones is controlled by the dominance of wind-generated waves out of the west (controlling the overall energy levels) and the resulting differences in subaqueous slope gradients (which affect the nearshore wave energy levels).

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