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SAND DISPERSAL IN EASTERN AND SOUTHERN LAKE ONTARIO[1, 2]

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ABSTRACT: A sediment dispersal model is constructed using parameters derived from beach and lake samples obtained from an area with a known point source and dispersal direction. Mean size and percent of fine-grained heavy minerals decrease whereas sorting and kurtosis values increase in direction of transport. Skewness, percentages of both "fines" and coarse-grained heavy minerals are less useful as indicators of transport direction.

The model also provides for comparisons of sample population means and variances of adjacent beach and lake deposits. Most values are greater for the beach populations if compared with their corresponding subaqueous counterparts. If the beach and lake population means of an area are compared with those from its source area, mean size is larger, percentage of fine-grained heavies is greater, kurtosis is lower (beach only) and sorting is poorer in the source area.

The model is compared with the entire American shoreline of Lake Ontario as well as four regions divided upon differences in the shoreline and nearshore features. They are the: Niagara (subaqueous delta, till cliffs), Rochester (subaqueous drumlins and sand sheets), Oswego (small sand patches, till cliffs), and Eastern shore (sand beaches, dunes, and a subaqueous sand sheet). The net sand transport has been eastward along the southern shore, then northward along the eastern shore. The sands of the Niagara delta have been derived from reworking during transgression while those on the adjacent beaches were derived from shoreline tills. The sands in the Rochester area have moved shoreward, probably from the eroded subaqueous drumlins offshore. The eastern shore sands show no lakeward transportation but were derived from the Oswego region in the past. A diminishing supply of sand in the source areas will result in a diminutation of beaches unless a substantial lowering of the lake level takes place.

INTRODUCTION

A general framework of sedimentary facies in nearshore areas of southern and eastern Lake Ontario has been constructed from sample descriptions and geophysical data taken during two lake cruises in 1968 and 1969, and from preliminary textural and mineralogical analyses of these samples (Sutton, Lewis, Woodrow, 1970). The southern and eastern nearshore of Lake Ontario consists of a shelf averaging two miles in width and with a distinct shelf edge at an average depth of 50 feet. Four large, isolated sand deposits occur on the shelf; one off the mouth of the Niagara River, the second offshore from Hamlin Beach State Park, the third off the mouth of the Genesee River, and the fourth along the eastern shore (Fig. 1). Elsewhere, small, isolated sand patches occur on the shelf otherwise characterized by a bedrock, till or boulders. Mud typically occurs lakeward of the shelf edge (C. F. M. Lewis and McNeely, 1967).

For convenience of discussion, the shore and nearshore shelf have been divided into four regions on the basis of shoreline topography and sediment type (Fig. 1). These regions are: (1) Niagara, (2) Rochester, (3) Oswego, and (4) Eastern shore. The major distinguishing features of each are listed in Table 1. The differences in the southern shoreline characteristics, including the isolated nature of the sand deposits has been cited as evidence for a complex depositional and erosional history.

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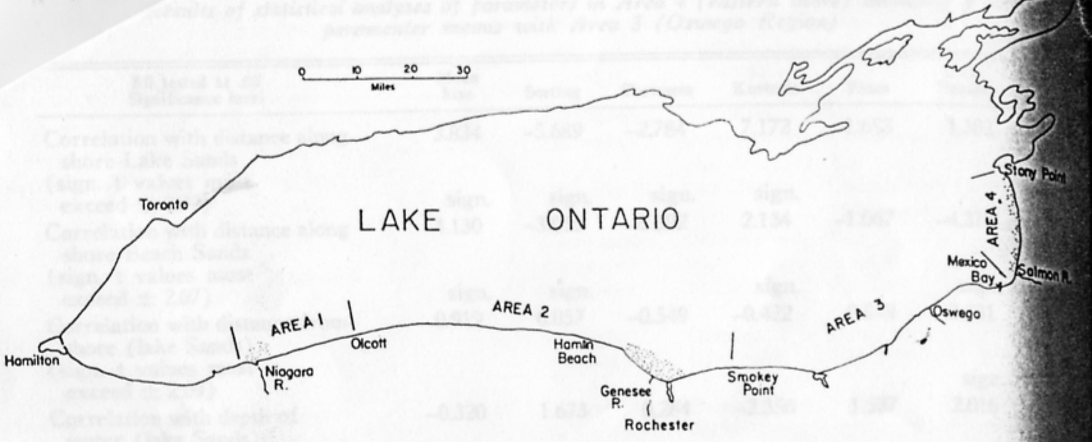

FIG. 1.—Index map of Lake Ontario showing major sand deposits and study areas along the southern and eastern shore.

In earlier studies, Sutton, Lewis and Woodrow (1970, 1972) considered the distribution of sands as well as the general characteristics of the eastern and southern nearshore lake bottom. These studies dealt in passing with the origin and distribution of the sands. It is the purpose of this paper to examine these aspects in greater detail. For this purpose, a sediment dispersal model was developed that would indicate the direction of sand transport and source of the sands. The model is compared with the distribution of textural parameters in the entire eastern and southern nearshore area as well as with its natural subdivisions. The results are used to gain an insight into the history of the basin and served as a basis for predicting changes in the sand distribution and supply.

PREVIOUS STUDIES

In studies of the Canadian shore, Rukavina (1969, 1970) suggests that local erosion of shore bluffs is a source for deposits west of the Niagara River, with the sediment accumulating by longshore drift adjacent to the Burlington bar. Along the northern shore the sediment is derived from local streams, shoreline bluffs and submerged tills. Net sediment transport is to the east. The authors' studies along the southern shore indicate that the potential sand sources are the Niagara and Genesee Rivers and the shoreline bluffs, submerged tills, and sand deposits at Hamlin, Rochester and Mexico Bay. Net transport is east only to Mexico Bay and then north along the eastern shore (Fig. 1). A study recording textural changes at selected sites between Toronto and Burlington, Ontario indicates the influence of local sources but is inconclusive relating trends of directional transport (Coakley, 1970).

Data relating variations of mineralogy of shore and nearshore sands to studies of directional transport are few and general in nature. Changes in trends of percent heavy minerals has been related to sources and directions of currents in southern shelf sands by Sutton, Lewis, and Woodrow (1970) and related to progressive sorting for beach sands between Webster and Oswego, New York by Coch (1961). According to Coakley (1970) variations of mineralogic characteristics of sand bodies did not differ significantly. Thomas (1969) explains a progressive qualitative nearshore-to-offshore loss of calcic plagioclase and enrichment of potassic feldspars as the result of chemical weathering that is related to length of time of transport. Glacial materials derived from coastline erosion were designated as the only source of the sediments. In contrast, Rubin (1972) found a change in the amount of plagioclase parallel to the shore which he explained as selective sorting due to differences in mineral densities. Studies of heavy minerals in the same coastal areas indicate the Niagara River as a supplier of monoclinic pyroxene to Lake Ontario and that there is a progressive loss of monoclinic pyroxene and enrichment of hypersthene from west to east (Selleck, 1972). He also found that the frequency of denser heavy minerals, interpreted as lag minerals, decrease shoreward at several sites indicating that the movement of sand is in that direction.

TABLE 1.—*Distinguishing features of the shoreline and subaqueous shelf in each region*

Region	Shoreline Features	Shelf Features
1. Niagara	Low till cliffs	Subaqueous delta
	Bedrock outcrops	Gravel sand deposit
	Gravel beaches—convex shoreline	Gravels and sands
2. Rochester	Tills, bedrock—convex	Sand bar and sand plain
	Minor gravel beaches	Eroded drumlins
	Barred bays and ponds—concave shoreline	
	Extensive sand beaches	
3. Oswego	High till cliffs—convex shoreline	Small, isolated sand deposits
	Bedrock	Bedrock, boulder and cobble gravels
	Boulder and gravel beaches, rare sand	
4. Eastern Shore	Barred bays and ponds	Continuous sand plain
	Extensive sand beaches, occasional gravel beach	
	High dunes on bars	

METHOD OF STUDY

A total of 151 sediment (67 shore, 84 lake) samples were collected, dried and split. One split of each sample was sieved at ¼ phi intervals with the fraction finer than 62 μM retained and weighed as "fines." Standard moment measures were computed to determine mean size, standard deviation (sorting), skewness and kurtosis. A second split was separated into two fractions (coarser and finer than 250 μM) and the percent of magnetically separated heavy minerals was determined for each fraction. Ten parameters were then available for use in constructing the model:

Mean size
Sorting
Skewness
Kurtosis
Percent of fines
Percent of coarse heavies
Percent of fine heavies
Distance from Niagara River
Distance offshore
Depth of water

In order to determine progressive changes of a given parameter or relations between parameters, several statistical tests were employed. A correlation coefficient (Pearson Product-moment) was computed for each pair of parameters for all lake and shore samples as well as paired parameters within each area. A student-T test was employed in order to compare "means" of the same parameter in adjacent populations or subpopulations as well as the significance of the correlation coefficient. Similarly, an F test was used to compare variances. All statistics were tested at the .05 level of significance. Procedures followed are described in Sokal and Rohlf (1969); statistical tables used were those of Rohlf and Sokal (1969).

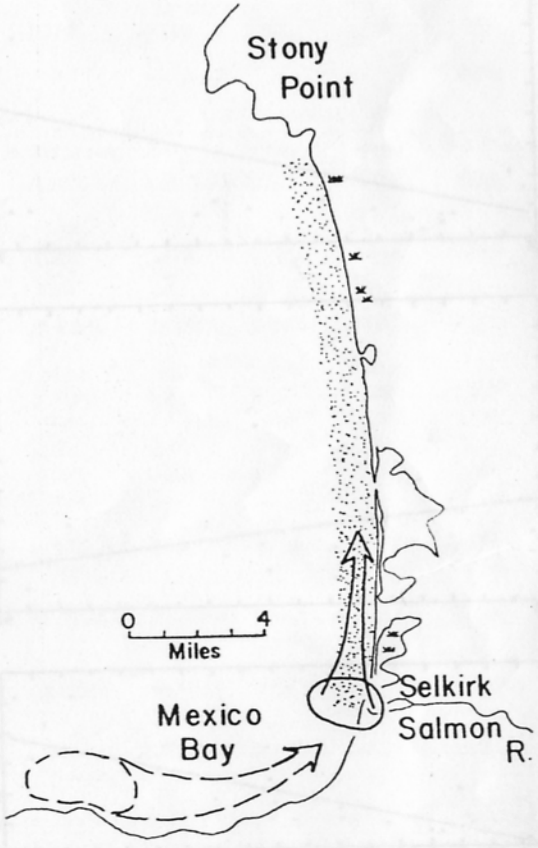

FIG. 2.—Eastern shore area (Area 4) of Lake Ontario.

CHARACTERISTICS OF SEDIMENT DISPERSAL MODEL

The eastern shore extending from Mexico Bay on the south to Stony Point on the north (Fig. 1) contains the largest sand deposit considered in this study and its bathymetric and topographic characteristics provide a relatively *esults of statistical analyses of parameters in Area 4 (eastern shore) including a comparison of parameter means with Area 3 (Oswego Region)*

All tested at .05 Significance level	Mean Size	Sorting	Skewness	Kurtosis	Fines	C-Gr. Heavies	F-Gr. Heavies
Correlation with distance along shore-Lake Sands (sign. t values must exceed ± 2.09)	3.834 sign.	–5.689 sign.	–2.784 sign.	7.172 sign.	–1.688	1.302	–2.945 sign.
Correlation with distance along shore-Beach Sands (sign. t values must exceed ± 2.07)	4.130 sign.	–3.055 sign.	–0.092	2.134 sign.	–1.067	–4.370 sign.	–6.879 sign.
Correlation with distance from shore (lake Sands) (sign. t values must exceed ± 2.09)	0.919	0.057	–0.549	–0.422	0.848	3.331 sign.	0.692
Correlation with depth of water (lake Sands) (sign. t values must exceed ± 2.09)	–0.320	1.673	0.284	–2.356 sign.	1.537	2.016	2.322 sign.
Comparison of Means: Beach vs. Lake (Probability values)	0.000 sign.	0.250	0.060	0.005 sign.	0.001 sign.	0.001 sign.	0.809
Comparison of Variances Beach vs. Lake	4.863 sign.	3.614 sign.	1.044	3.801 sign.	1207.3 sign.	3.681 sign.	4.450 sign.
Critical F value	2.37	2.37	2.37	2.33	0.000	2.32	2.37
Comparison of Means of Beach Parameters Area 3 vs. Area 4 (Prob. values)	0.00332 sign.	0.00060 sign.	0.38420	0.03307 sign.	0.17356	0.00000 sign.	0.00936 sign.
Comparison of Means of Lake Parameters Area 3 vs. Area 4 (Prob. values)	0.01712 sign.	0.02852 sign.	0.51708	0.55967	0.35339	0.00573 sign.	0.00002 sign.

simple context in which to establish relationships between water depth, longshore drift, net sediment transport and corresponding changes in textural and compositional parameters. In this deposit sand is being removed from the south end of the deposit and shifted northward (Fig. 2). The southern edge of the sand mass is located at Selkirk, New York where the Salmon River contributes some sand. South of Selkirk the beach sediments are gravels and gravelly sands. North of Selkirk a sandy beach extends continuously as a gentle arc 18 miles in length and sands on the adjacent shelf form a smooth, continuous sheet paralleling the shoreline. The few interruptions in the beach are inlets to bays or the mouths of low-gradient streams. These streams contribute only very fine sediment to the lake since they drain swamps and are floored with mud (Sutton, Lewis, Woodrow, 1972). Thus, sand supplied from the south shore of Lake Ontario to the west is moved northward along the eastern shore by currents diverted to that direction at Mexico Bay. This simple transport system has, in effect, a point source and any variations in its textural statistics down current must reflect dispersal within the environment and not provenance.

All ten parameters were calculated for 20 samples each of beach and lake deposits collected by the writers in 1968 and 1969 (Sutton, Lewis, Woodrow, 1970). Results of the analyses are presented in Table 2 including a comparison with those from the Oswego region to the southwest (Fig. 1).

Examination of the data in Table 2 reveals that some of the parameters analyzed are much more sensitive than others as descriptors of sediment modification with longshore transport. Mean size and percentage of fine-grained heavy minerals decreased while sorting and kurtosis values increased (Fig. 3). In contrast, the percent of fines and skewness were relatively insensitive as descriptors of change. The statistical analysis of coarse-grained heavies duplicates fine-grained heavies in many cases and, because of the less common occurrence of coarse-grained heavies, they have been omitted.

Interpretation of the data for the more sensitive parameters forms the basis for the sediment dispersal model (Table 3). As expected for a model of longshore transport, little or no correlation was found between the parameters and either "distance from shore" or "depth of

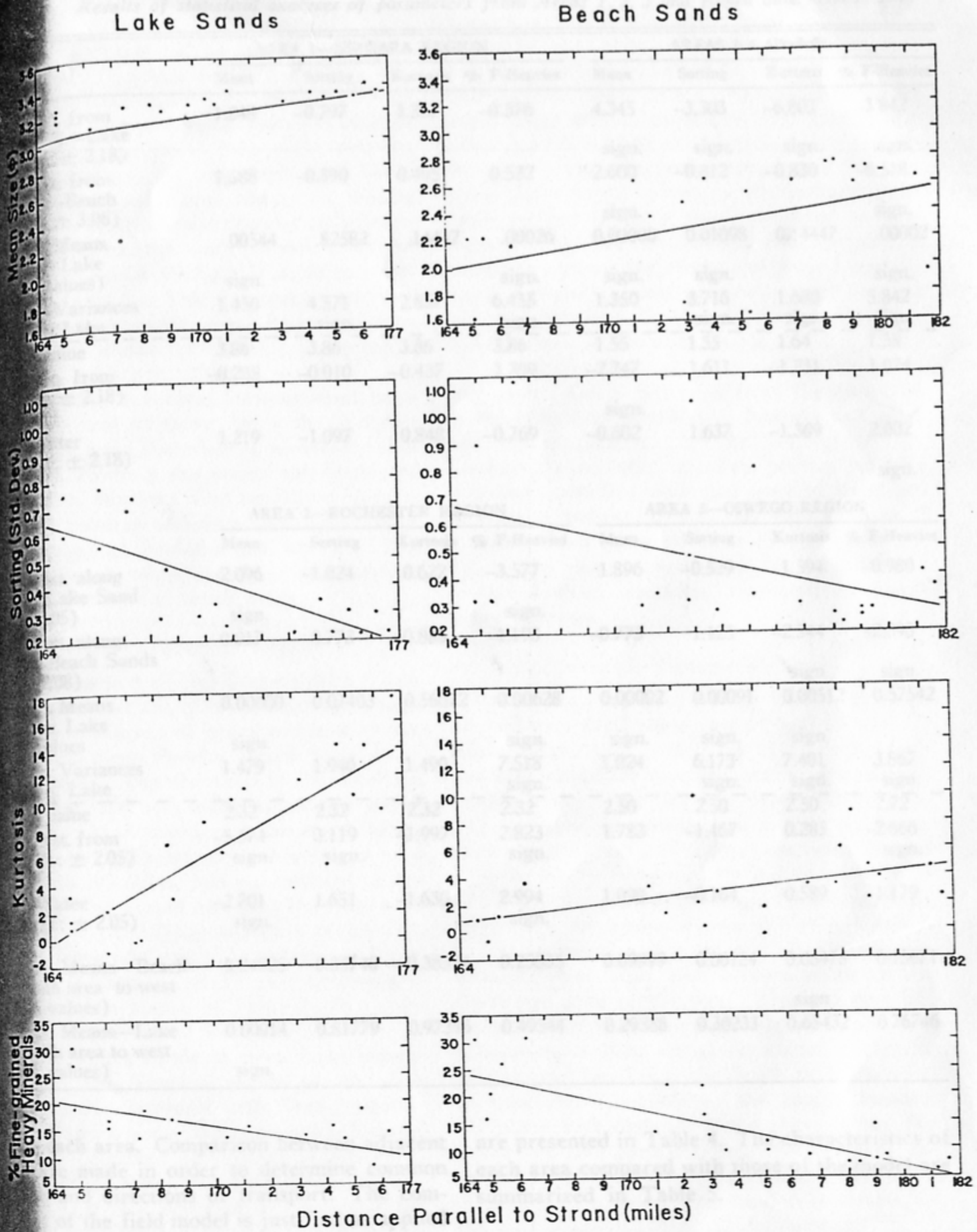

FIG. 3.—Trends of selected parameters from 164 miles at Selkirk to 177 miles near Stony Point (distances from Niagara River). All lines are machine fitted.

TABLE 3.—*Significant characteristics of the sediment dispersal model*

	Mean Size	Sorting	Kurtosis	Percentage Fine-Grained Heavy-Minerals
Change with distance of transport—Lake Sands	Decreases	Increases	Increases	Decreases
Change with distance of transport—Beach Sands	Decreases	Increases	Increases	Decreases
Change with distance from Shore	No Correlation	No Correlation	No Correlation	No Correlation
Change with water depth (Lake Sands)	No Correlation	No Correlation	Decreases	Increases
Comparison of means of Beach and Lake Sample Populations (Lake Sands)	Greater for Beach	No Difference	Greater for Lake	No Difference
Comparison of variances of Beach and Lake Sample Populations	Greater for Beach	Greater for Beach	Greater for Beach	Greater for Beach
Comparison of Means of Beach Parameters with those of source or sediment supply	Larger in Source	Poorer in Source	Lower in Source	Higher in Source
Comparison of Means of Lake Parameters with those of source or sediment supply	Larger in Source	Poor in Source	No Difference	Higher in Source

water." If such correlations were found in another area, considerable doubt would be cast upon the hypothesis that longshore transport was the dominant transport pattern. On this basis the two statistical manipulations are retained as an integral part of the model. Because of the inherent environmental differences between a beach and lake bottom, differences between their parameter populations may be expected. Significant differences in the means and variances were found and incorporated into the model.

A comparison of means of population parameters for adjacent areas can provide an additional mechanism for determining direction of transport and sources of sand. For example, knowing that the mean sample size decreases in direction of transport, an area of source—or sediment supply (here called A) should have a mean sample population size, either similar to or greater than an area receiving the sediment (here called B). If the means of beach samples in Area A are compared with the means of beach samples in Area B and the latter are significantly larger, strong evidence has been compiled to reject the hypothesis that A is the source of the sand for B. A similar result comparing their lake sands would provide similar evidence for rejection. Table 2 demonstrates the comparison of parameter means in Area 4 (Eastern shore) with the corresponding means of Area 3 to the west, the suspected source of the bulk of the sands. As predicted, the mean size and percent of fine-grained heavies are greater in Area 3 for both beach and lake sands, the sorting and kurtosis are better in Area 4 except for kurtosis of lake sands which registers no significant difference. Although a similar comparison of variances was made, the trends were insignificant and difficult to interpret. For these reasons, the comparisons were omitted from the model.

The Salmon River enters Lake Ontario at the southern end of the eastern shore deposit. The river is not considered a major source of sediment because beaches adjacent to the river mouth consist primarily of cobbles and pebbles. Plots of sediment parameters of samples from the lake fail to display disruption of the trend of the parameters in the vicinity of the river mouth.

In summary, the model constructed considered variations in only four sediment sample parameters. These change in direction of transport (either parallel or normal to the shore) or with water depth. The model not only provides for significant differences between beach and lake parameters but also provides for predictable differences between the average sample in the model if compared with an average sample from a possible source area.

COMPARISON OF DISPERSAL MODEL WITH SOUTHERN SHELF AREAS

Those parameters used to characterize the model were determined for each of the areas along the south shore of Lake Ontario in order to delineate sources and directions of transport within each area. Comparison between adjacent areas are made in order to determine common sources and directions of transport. The comparison of the field model is justified as applied to areas of comparable dimensions in the same basin that have been affected by similar climatic conditions, and wave and current energies which modify similar sediments. Results of statistical analyses of the significant parameters for each area, comparison between adjacent areas, and pooled data for the entire shoreline are presented in Table 4. The charac
each area compared with those of the
summarized in Table 5.

Area 1—Niagara Region

The physiographic features of th
summarized in Table 1. Potential
sand include: (1) the Niagara
shoreline till cliffs west of the rive
shallower portions of the nearshore l

TABLE 4. *Results of statistical analyses of parameters from Areas 1, 2, 3 and pooled data (Ar*

	AREA 1—NIAGARA REGION				AREAS 1–4 (Pooled)		
	Mean	Sorting	Kurtosis	% F-Heavies	Mean	Sorting	Kurtosis
Corr. Dist. from Niagara R.—Lake Sands (t: ± 2.18)	1.248	–0.797	1.351	–0.376	4.345 sign.	–3.303 sign.	–6.803 sign.
Corr. Dist. from Niag. R.—Beach Sand (t: ± 3.06)	1.388	–0.390	0.495	0.532	2.600	–0.812	–0.830
Compar. Means Beach vs. Lake (Prob. Values)	.00544 sign.	.82582	.14447	.00026 sign.	0.00000 sign.	0.01098 sign.	0.14447
Compar. Variances Beach vs. Lake	1.450	4.571 sign.	2.657	6.455 sign.	1.350	3.716 sign.	1.680 sign.
Crit. F value	3.86	3.86	3.86	3.86	1.55	1.55	1.64
Corr. Dist. from shore (t: ± 2.18)	–0.235	–0.010	–0.437	1.399	–2.747 sign.	1.611	–1.231
Corr. Water Depth (t: ± 2.18)	1.219	–1.097	0.848	–0.769	–0.602	1.637	–1.369
	AREA 2—ROCHESTER REGION				AREA 3—OSWEGO REGI		
	Mean	Sorting	Kurtosis	% F-Heavies	Mean	Sorting	Kurtosis
Corr. Dist. along Shore—Lake Sand (t: ± 2.05)	2.096 sign.	–1.024	0.622	–3.577 sign.	1.896	–0.529	1.594
Corr. Dist. along Shore—Beach Sands (t: ± 2.08)	0.017	0.773	–0.886	–1.193	–0.773	1.125	–2.344 sign.
Compar. Means Beach vs. Lake Prob. values	0.00000 sign.	0.07403	0.56072	0.00628 sign.	0.00002 sign.	0.00091 sign.	0.00512 sign.
Compar. Variances Beach vs. Lake	1.479	1.940	1.490	7.518 sign.	1.024	6.173 sign.	7.401 sign.
Crit. F value	2.32	2.32	2.32	2.32	2.50	2.50	2.50
Corr. Dist. from Shore (t: ± 2.05)	–5.574 sign.	3.119 sign.	–1.997	2.823 sign.	1.783	–1.467	0.285
Corr. Water Depth (t: ± 2.05)	–2.701 sign.	1.651	–1.630	2.994 sign.	1.090	–0.164	0.589
Compar. Means—Beach Par. with area to west (Prob. values)	0.24025	0.33740	0.38554	0.25035	0.09999	0.06124	0.03473 sign.
Compar. Means—Lake Par. with area to west (Prob. values)	0.00014 sign.	0.81779	0.97346	0.49544	0.29388	0.30233	0.6543

BLE 5.—*Comparison of model with Areas 1, 2, 3 and the entire southern and eastern shore. Blanks signify no correlation or no significant diffe*

Comparisons	AREA 1—NIAGARA REGION Mean Size	Sorting	Kurtosis	F-Grained Heavies	AREAS 1–4 SOUTHERN AND EASTERN LAKE ONTARIO Mean Size	Sorting	Kurtosis	F-Grained Heavies
Dist. from Niagra R. Lake Sands					Decreases	Increases		Decreases
Dist. from Niagra R. Beach Sands					Decreases			Decreases
Dist. from Shore					Increases			
Water Depth								Increases
Means of Beach and Lake Sands	Greater for Beach			Greater for Beach	Greater for Beach	Greater for Beach	Greater for Beach	Greater for Beach
Variances of Beach and Lake Sands		Greater for Beach		Greater for Beach		Greater for Beach	Greater for Beach	Greater for Beach

Comparisons	AREA 2—ROCHESTER REGION Mean Size	Sorting	Kurtosis	F-Grained Heavies	AREA 3—OSWEGO REGION Mean Size	Sorting	Kurtosis	F-Grained Heavies	MODEL Mean Size	Sorting	Kurtosis	F-Grained Heavies
Distance Along Shore Lake Sands	Decreases			Decreases					Decreases	Increases	Increases	Decreases
Distance Along Shore Beach Sands							Decreases	Decreases	Decreases	Increases	Increases	Decreases
Dist. from Shore	Increases	Decreases		Increases				Decreases				
Water Depth	Increases			Increases							Decreases	Increases
Means of Beach and Lake Sands	Greater for Beach			Greater for Beach	Greater for Beach	Greater for Lake	Greater for Lake		Greater for Beach		Greater for Lake	
Variances of Beach and Lake Sands				Greater for Beach		Greater for Beach	Greater for Lake	Greater for Beach	Greater for Beach	Greater for Beach	Greater for Beach	Greater for Beach
Beach Parameters with those of Sediment Supply							Higher in Source		Larger in Source	Poorer in Source	Lower in Source	Higher in Source
Lake Parameters with those of Sediment Supply	Larger in Source								Larger in Source	Poorer in Source		Higher in Source

strongly c̄ the corresponding characteristics

Data from 10 shore and 14 lake samples provided the results summarized in Tables 4 and 5.

The conspicuous fan-shaped deposit off the Niagara River is a subaqueous delta constructed from sands and gravels channeled through the river. An offshore bar expressed as a slight East–West topographic rise crosses the middle of the delta. No significant correlation between the textural parameters and distance from the river mouth, distance offshore or depth of water are noted (Table 5). This demonstrates a poor fit of the model assuming the Niagara River as the only point source but strongly suggests the influence of additional sources.

No correlation is evident between beach sample textures and distance from the Niagara River (Table 5). Therefore it is unlikely that the Niagara River is the major contributor of sand to these beaches. The nearshore shelf is an unlikely modern sediment contributor since it is composed of boulders and bedrock. The tills along the shoreline are the only remaining possible source of the beach sands.

Area 2—Rochester Region

The western part of this area exhibits a convex shoreline and till cliffs similar to Area 1 and a notable absence of nearshore sand except a large patch near Hamlin Beach State Park. Near Braddocks Bay the shelf is characterized by submerged tills and beach ridges that merge eastward into sand sheets near the mouth of the Genesee River. The adjacent shoreline is concave, has no till cliffs, and is composed of extensive sand and gravel beaches. Potential sand sources are (1) the Niagara region to the west, (2) subaqueous tills, and (3) the Genesee River. Data from 23 beach and 30 lake samples provided the results shown in Table 4 and a comparison with the model in Table 5.

The bulk of the sands of Area 2 are not derived from the Niagara region to the west. Comparison of the model with Area 2 characteristics shows a very poor correlation between changes of sediment parameters as related to distance along shore. The only supporting evidence for this is a decrease in mean size and percent of fine-grained heavies. Small patches of beach sand in the western part of Area 2 are derived from the adjacent shoreline tills just as in Area 1.

The subaqueous tills have provided most of the beach and lake sands in this area. Important changes in the sediment parameters as related to distance from shore and water depth contrast

of the model. Lakeward increases in mean size and percent of fine-grained heavies are primary evidence that sand is being transported shoreward. The obvious source of this sand is the subaqueous tills. The model shows that sorting increases in the direction of transport. In Area 2 the decrease in sorting with distance from shore, further supports the concept of an offshore source. The similarities of the means and variances between the model and Area 2, namely mean size and percent of fine-grained heavies indicate that both beach and lake sands were derived from a common source.

The Genesee River is not a modern source of lake sands. Cores retrieved from the river bed at the mouth contained only fine-grained muds and organic matter. In the vicinity of the Genesee River, the concave portion of the shoreline coincides with the area of sand accumulation indicating that this part of Area 2 is acting as a sediment trap (Figs. 1 and 5). Sands are moved shoreward but are further protected from eastward transport by longshore currents.

Area 3—Oswego Region

A convex shoreline with high till cliffs fringed by a shelf comprised of bedrock and till characterizes this area (Fig. 1). Both beach and lake sands are rare and occur as small isolated patches. The possible sand sources are: (1) the sand accumulations in the Rochester region to the west (2) the subaqueous tills, and (3) the till cliffs along the shoreline. A total of 14 beach and 14 lake samples were analyzed to produce the results shown in Tables 4 and 5.

The scattered sands of this area were not derived from large sand accumulations in the Rochester area to the west. The sediment parameters fail to demonstrate a significant correlation with distance along shore. Only the fine-grained heavies in the beach sands decrease as expected. Contrary to the model, kurtosis decreases with distance along shore. Also, the beach and lake parameters fail to show the expected differences if compared with those of Area 2 to the west. The local tills remain as the only possible source of the sands.

The small isolated sand patches in the lake have been locally derived from the subaqueous tills. There is no correlation of sediment parameters with distance from shore or depth of water. Only fine-grained heavies decrease with distance from shore, a pattern suggesting an onshore source. However, the results of a of $\bar{x}_a + s^2$ ~ ag beach

sands in Area 2 provides a pattern that ely resembles that of the model. It must be remembered that the model provided no onshore source for its lake sands. The similarity here with the model is cited as additional evidence that the beaches were not the source of the lake sands.

The small, scattered patches of beach sands are locally derived from their immediately adjacent till cliffs. There is no evidence of onshore movement of lake sand such as that demonstrated in Area 2, nor is there any evidence of appreciable longshore drift. Coch (1961) found considerable variation in texture and mineralogy in a set of closely spaced samples from this region. His results further substantiate the local origin of the sand patches.

It may be recalled that in the development of the model, Area 3 served as a source for sands along the eastern shore. Yet it has been demonstrated that the Oswego region is not presently contributing the major bulk of sands to the eastern shore. Therefore, it can only be concluded that the eastern shore sands migrated to that area sometime in the past.

GENERAL SEDIMENT DISTRIBUTION PATTERNS AND INTERPRETATIONS

The statistical data have been combined from all areas in order to develop generalizations about changes in sediment parameters along the southern and eastern shoreline (Tables 4 and 5).

1. The mean size and percent fine-grained heavies decrease in the direction of transport.
2. The sorting of lake sands increases in the same direction.
3. The only changes of sediment parameters with regard to distance from shore or depth of water are an increase of mean size and an increase of fine-grained heavies.
4. Comparison of means and variances of beach and lake sands provides results very similar to those in the model signifying that the statistics are reflecting environmental differences between the beach and the lake.

Although there are local differences, the lake sediment transport system conforms fairly well with the model and is considered to be the result of the easterly surface circulation. Subaqueous tills appear to have been an important source of sand. Rivers have been a less important contributor of sand than expected. The small patches of beach sand at the base of the till cliffs in Areas 1 and 3 appear to be the result of erosion of those tills and are not part of a continuous train of sand migrating by littoral drift. These beach sands do not appear to be the primary source of the sand on the adjacent shelf.

It is now possible to draw some conclusions about the origins, history and fate of the three largest sand deposits along the southern and eastern shore. The sand bar located near the northern edge of the Niagara delta, the offshore deposit at Hamlin Beach State Park and sand deposits to the east (Fig. 1) represent remnants of older shoreline deposits formed during a stillstand approximately 5000 years ago which are now preserved after subsequent flooding of the southern shore (Sutton, Lewis, Woodrow, 1972). The Niagara subaqueous delta deposit has formed during the past 5000 years. The sand sheets in the Rochester deposit would be less than 5000 years old because the southern shoreline has been flooded within that time. The sand was derived from eroding subaqueous tills and moved shoreward.

Subaqueous tills have been the major supplier of sand during the rise of lake level. Lag boulder beds cover the bottom and retard further erosion of the till resulting in a diminishing supply of sand available for transport. As a result, the present sand bodies are being starved and will diminish in size unless a lake level change occurs. A rise in lake level would result in increased erosion rate of shoreline tills but these tills contain only small amounts of sand so the supply to the beaches would not be increased greatly. The rise in level would result in the increased water depths over the present subaqueous tills and their small contributions would be further decreased, offsetting in part the increased contributions from the till cliffs.

A lowering of lake level would provide the only mechanism for an increased sand supply. Sands in the Niagara River delta and Rochester area would be subjected to increased wave and current erosion, adding sands to the shoreline down-current. The limits of the lake level are controlled by the limits, both natural and artificial, in the St. Lawrence River so that decreasing natural sand beaches are forecast for the southern and eastern Ontario shoreline.

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