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ERODIBILITY OF LAKE ERIE UNDISTURBED TILLS

by

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MANAGEMENT PERSPECTIVE

The management of shorelines composed of actively eroding cohesive sediments requires, as a foundation, a firm understanding of the erosion processes. An instrument has been developed and used to measure the erosion resistance of various tills from Lakes Erie and Ontario. The instrument provides a means of rapidly determining relative erodibilities of undisturbed cohesive tills from diverse locations, and as such is a useful tool in investigating erosion processes.

Chief
Hydraulics Division

Perspective-gestion

Pour mener à bien l'aménagement de rives formées de dépôts morainiques cohésifs en proie à une érosion active, il faut d'abord comprendre les mécanismes à l'oeuvre. On a mis au point un instrument servant à mesurer la résistance à l'érosion des différentes formations morainiques des lacs Erié et Ontario. L'instrument permet de déterminer rapidement l'érodabilité relative des dépôts morainiques cohésifs non perturbés provenant de divers endroits et s'avère donc utile pour l'étude des mécanismes de l'érosion.

Le chef,
Division de l'hydraulique

ERODIBILITY OF LAKE ERIE UNDISTURBED TILLS

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ABSTRACT

Forty-five laboratory erodibility tests using a rotating-cylinder apparatus were conducted on 10 cm dia., 10 cm long cylindrical samples of undisturbed cohesive tills of low sensitivity. The samples were obtained from toe portions of actively-eroding bluffs at three sites on the north-central shore of Lake Erie. In each test, the erodibility was characterized by both the critical shear stress, τ_c, and the erosion rate, $\dot{\varepsilon}$. In addition, index-property tests (particle size, natural water content, Atterberg limits and vane shear strength) were carried out. The most consistent results and best correlations with sediment index properties were obtained using only τ_c to characterize sediment erodibility. The analysis of variance confirmed statistically significant difference for two different till formations, while no significant difference was obtained for two sites within the same formation. Although $\dot{\varepsilon}$ values are highly variable for individual samples, averaged values show consistent direct relationship between τ and $\dot{\varepsilon}$. The two Lake Erie tills are more resistant to erosion, both in terms of τ_c and $\dot{\varepsilon}$, than the Halton Till from the Stoney Creek site in Lake Ontario.

RÉSUMÉ

On a mené en laboratoire 45 épreuves d'érodibilité à l'aide d'un appareil à cylindre rotatif utilisant des carottes de 10 cm de diamètre et de 10 cm de long de dépôts morainiques cohésifs non perturbés à faible sensibilité. Les échantillons ont été recueillis au pied de falaises à érosion rapide à trois sites au centre de la rive septentrionale du lac Erié. Pour chacune des épreuves, l'érodibilité se caractérisait par la tension de cisaillement critique, τ_c, et le taux d'érosion, $\dot{\varepsilon}$. On a aussi mené des épreuves portant sur propriétés géotechniques (granulométrie, teneur en eau, limites d'Atterberg et résistance au cisaillement de l'aube). On a obtenu les résultats les plus constants et les meilleures corrélations avec les propriétés de l'indice des sédiments avec τ_c seulement, qui caractérise l'érodibilite des sédiments. L'analyse des écarts de variance a confirmé une différence statistique importante pour deux formations morainiques distinctes, alors qu'on n'a relevé aucune différence marquée pour deux sites de la même formation. Bien que les valeurs $\dot{\varepsilon}$ aient été très variables pour des échantillons individuels, la moyenne des valeurs démontre une relations consistante direct entre τ_c et $\dot{\varepsilon}$. Le deux formations morainiques du lac Erié résistent davantage à l'érosion, en termes de τ_c et de $\dot{\varepsilon}$, que celles de Halton du site de Stoney Creek dans le lac Ontario.

INTRODUCTION

Quantitative measurements of sediment erodibility should prove useful for interpretation of measured subaerial and subaqueous erosion along cohesive shores, as well as for attempts to model the complex processes of bluff recession. On the basis of laboratory and field data, Sunamura (1977) proposed a basic relation for the recession of rock cliffs of the form

$$\frac{dx}{dt} \propto \ln\left(\frac{f_w}{f_r}\right) \qquad (1)$$

where dx/dt = the recession rate, f_w = the erosive force of waves and f_r = the resisting force of cliff material. According to Sunamura, f_r is controlled by the mechanical properties of the rock cliffs (e.g., compressive strength, tensile strength and wear resistance) and by rock structure (e.g., joints, faults and stratification). Physical reasoning suggests that the same concept, with appropriate modifications, should be applicable to predominantly cohesive shores of the lower Great Lakes.

A previous study (Dick and Zeman, 1983) applied spatially limited data from the Lake Erie north shore and proposed a linear relationship between the work done by the waves, which is strongly dependent on lake-level fluctuations, and measured average toe recession. The erosion resistance of sediments occurring at the toe of bluffs is therefore of particular interest.

Considering many intricacies of the shore-recession process, the objective of the present paper is deliberately limited to measurements of f_r for undisturbed cohesive sediments that occur at the toe of the bluff and in the nearshore zone. The intent is to express f_r in terms of the critical shear stress, τ_c, and the erosion rate, $\dot{\varepsilon}$, the two most common parameters used in the literature concerned with erodibility of cohesive sediments. Published results for cohesive sediments of comparable consistency to that of the glacial and glaciolacustrine sediments that form cohesive shores in the Great Lakes region are scarce, and the values of the critical shear stress obtained from these studies vary widely with different researchers (Kamphuis and Hall, 1983). It appears that this wide discrepancy is due not only to the variable geotechnical properties of sediments tested, but also to the differences in the testing procedures used, sample-preparation techniques, and to the differences in the definition of the critical shear stress (Zeman, 1983a).

METHODS

Sampling and Sample Preparation

The samples used for laboratory tests described in the present paper were obtained from three sites located on the north central shore of Lake Erie (Figure 1). All three sites undergo active shore erosion in the general absence of granula beach deposite. The location of the three sampling sites in reference to the bluff stratigraphy of the north central shore is shown in Figure 2.

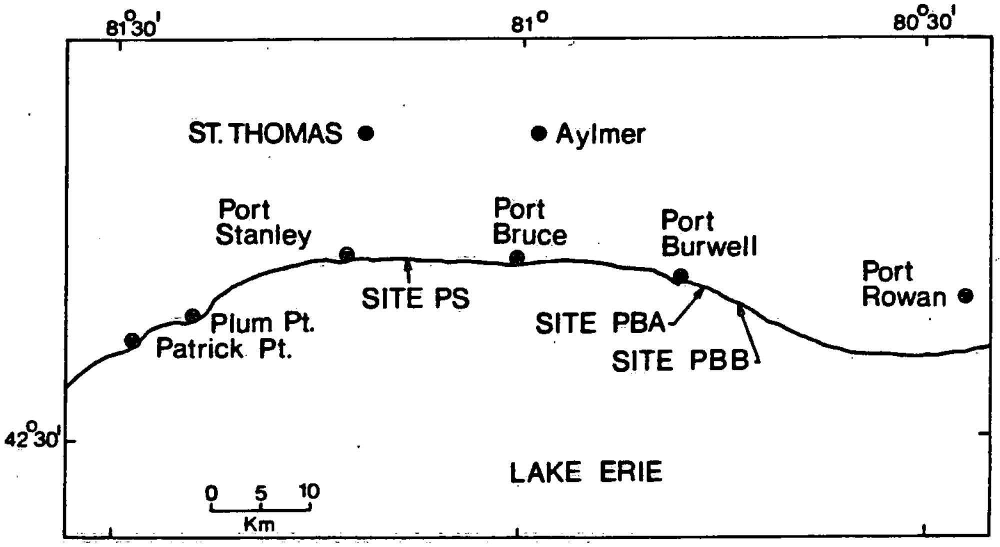


Fig. 1. Location of sampling sites.

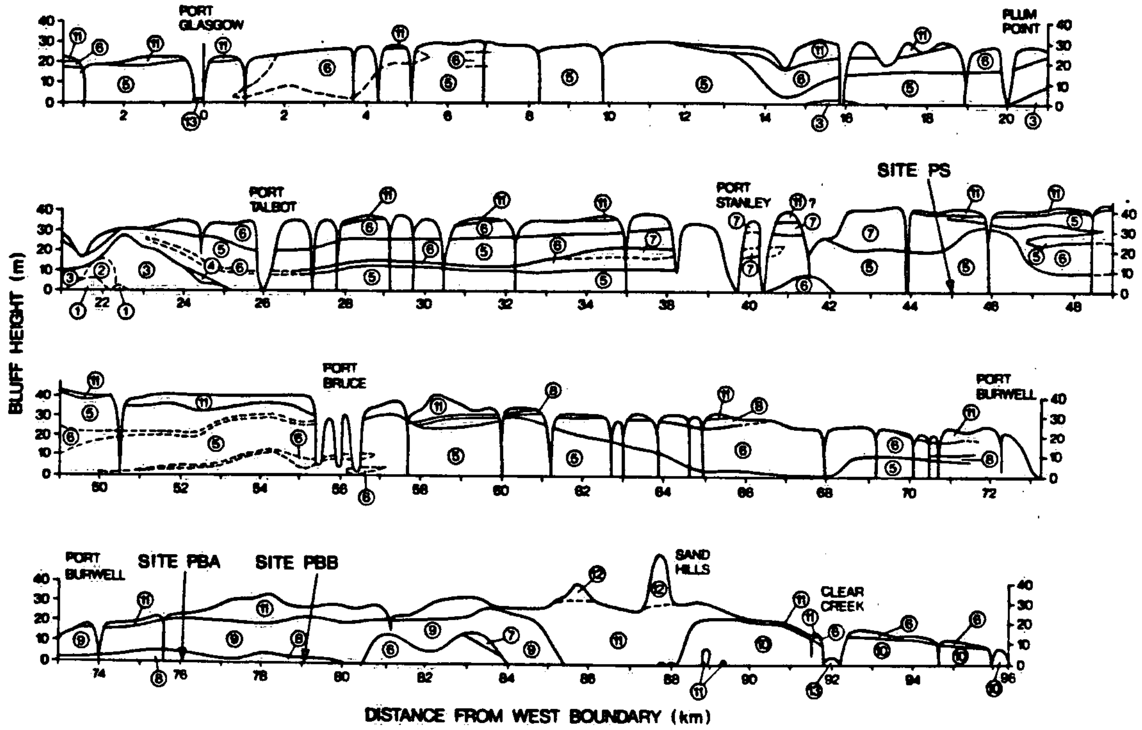


Fig. 2. Three sampling sites in reference to bluff stratigraphy.

TABLE 1. LEGEND FOR BLUFF STRATIGRAPHY (FIGURE 2)

No.	Stratigraphic Unit	Tentative Age Correlation
1	Glaciolacustrine Silt and Clay	Port Talbot Interstadial
2	Sand and Gravel	Plum Point Interstadial
3	Catfish Creek Till	Nissouri Stadial
4	Sand	Erie Interstadial
5	Port Stanley Till	Port Bruce Interstadial
6	Glaciolacustrine Silt and Clay	Port Bruce Stadial and Mackinaw Interstadial
7	Glaciolacustrine Silty Sand to Sand	Port Bruce Stadial and Mackinaw Interstadial
8	Waterlain Till	Port Bruce Stadial or Early Mackinaw Interstadial
9	Glaciolacustrine Silt and Sandy Silt	Early Mackinaw Interstadial
10	Wentworth Till	Early Mackinaw Interstadial
11	Sand	Mackinaw Interstadial to Recent
12	Dune Sand	Recent
13	Alluvium	Recent

The first site (Site PS) is located in the vicinity of the Elgin County Water Intake Plant. The geology and geotechnical conditions at the site are described in detail in Bou (1975) and a sumarized description is contained in Quigley et al. (1977). The site is characterized by 40-m high bluffs, which fail in huge rotational slides as a result of continuous toe erosion. All samples collected from the site were taken from the toe area of the bluffs, which is formed by the Port Stanley Till (Dreimanis, 1967; Zeman, 1980). During sampling, care was taken to avoid slumped, fissured and desiccated material. The samples were collected using 15.2 cm (6 in.) dia. heavy-duty plastic tubes, which were slowly hammered into the in situ bluff stratum. In total, 30 cores, each approximately 15 cm long, were collected at this site. The cores were wrapped in a cheesecloth, waxed immediately after collection, and transported to the laboratory storage room during the week of sampling.

The other two sites (PBA and PBB) are located in the area east of Port Burwell, where a clayey waterlain till occurs at the toe of the bluffs. The extent of this deposit is known from previous studies (Zeman, 1980). Stratigraphically, the deposit is correlated with a prograding deltaic sequence, which occured possibly during the latter part of the Port Bruce Stadial and the Mackinaw Interstadial (Barnett, 1983). As the toe of the bluffs in this area was inaccessible, the cores were collected by divers using a hand-held till corer. Site PBA was located 4 m offshore on previously established survey line X14 of the NWRI erosion study site (Zeman and Thompson, 1982) and Site PBB was located 6 m offshore at the Elgin/Haldiman-Norfolk County line. The

15.2 cm dia. plastic tubes were pounded approximately 18 cm into the lake bottom using the till corer. The tubes were then dug out using a shovel, and sealed with plastic sheets and waxed cloth to prevent desiccation of the sediment surface. In total, 8 cores were collected from Site PBA and 12 cores from Site PBB.

All cores collected were stored in a temperature-controlled humid storage room at 4°C prior to testing. An aluminum cylindrical cutter was used to trim cores to the standard 10 cm dia. sample size. The top and the bottom of a sample were trimmed with a wire saw to the approximate height of 10 cm. Exact caliper measurements of the sample height were recorded as a part of the testing procedure. The sample was then carefully pierced with a thin stainless-steel shaft and metal end pieces were attached tightly to the sample. The sample with both end pieces was then immersed in distilled water for approximately 24 hours and sample weight was measured several times until no gain in sample weight was recorded as a consequence of sample immersion.

Geotechnical Identification Tests

The natural water content of all samples was determined using the standard ASTM procedure (D2216) and the results are reported in percent of oven-dry weight. The Atterberg limits were measured in accordance with procedures D423 and D424. The particle-size analyses were carried out using a combined pipette-Sedigraph method (Duncan and LaHaie, 1979). Vane shear strength measurements were performed using a Wykeham Farrance 2350 vane apparatus.

Erodibility Tests

The laboratory erodibility tests were carried out in the rotating-cylinder apparatus (Figure 3) which is of similar design to the equipment employed in several previous studies (Moore and Masch, 1962; Arulanandan et al. 1975; Chapuis and Gatien, 1985). In a test, a 10 cm dia., 10 cm long cylindrical sample is mounted coaxially inside a larger transparent cell. The cell is then filled with distilled water and rotated at preset speeds, which can go up to 2400 rpm. During rotation, the torque transmitted to the inside stationary cylinder is measured by a strain-gauge torque sensor with a digital indicator unit, which gives direct torque readings in newton-metres. In accordance with the procedure used in previous studies (Sargunam et al., 1973; Arulanandan et al., 1975), erosion rates are determined by the loss in mass of the sample after 60 sec periods of erosion. Both the torque and mass-loss are recorded at 50 rpm increments. The test is terminated when major degradation of the sample occurs or when the rotational speed reaches 1800 rpm.

The torque that is measured during the test is a total torque that has five components (Figure 4). Experiments indicated that the component T_{SH} is, for all values of rpm used, less than 0.001 N-m and can therefore be disregarded. A significant contribution to the torque is, however, the component T_E produced by viscous forces acting on the end pieces. Values of T_E at different speeds has been experimentally measured during the calibration of the apparatus (Zeman, 1984) and compared with boundary-layer formulae for laminar and turbulent

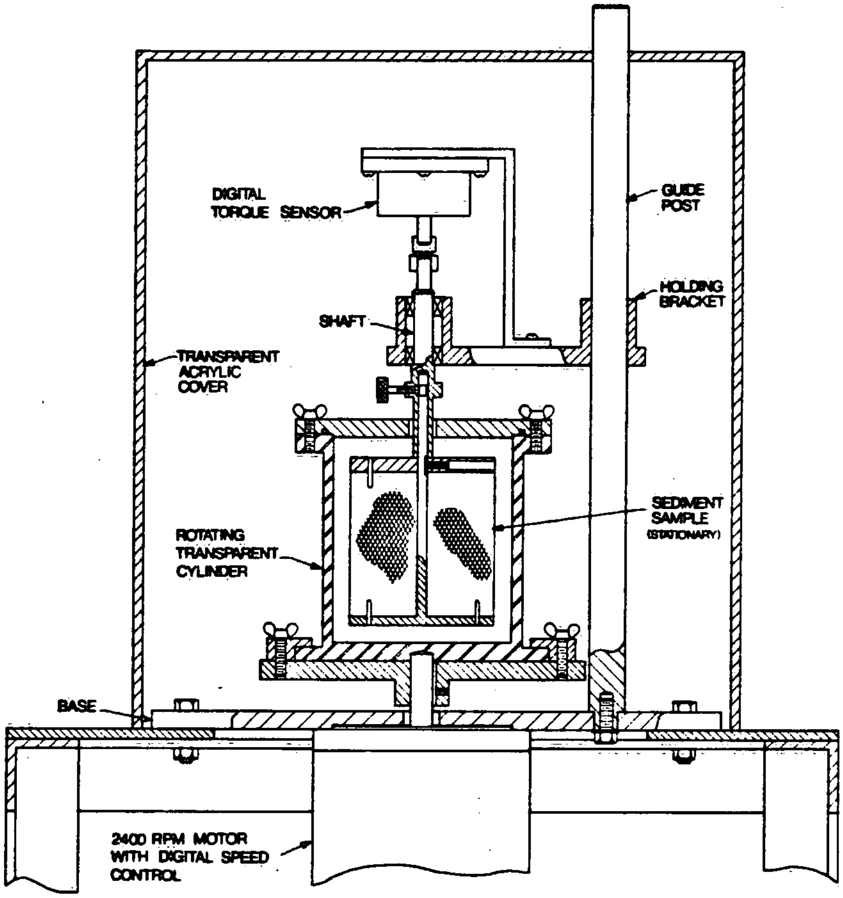


Fig. 3. NWRI rotating-cylinder apparatus.

flow for an analogous case of a rotating disk in a body of fluid (Schlichting, 1968). The very good agreement between theory and experimental measurements (Figure 5) suggests that no systematic errors occur during torque measurements. Additional evidence for this assertion is provided by two independent calibrations with different torque sensors that resulted essentially in the same parabolic relationship between the rpm and the total torque measured (Zeman, 1984). The net shear stress, τ_s, transmitted by the fluid to the sediment surface, is then computed from the following equation

$$\tau_s = \frac{T_s}{2r_1^{\,2}b'} \qquad (2)$$

where T_s = the torque applied to the sediment surface, r_1 = the radius of a sediment sample and b' = the length of a sample (Figure 6).

Within the context of the present paper, the critical shear stress, τ_c, is defined as the lowest τ_s value at which erosion is quantitatively detected.

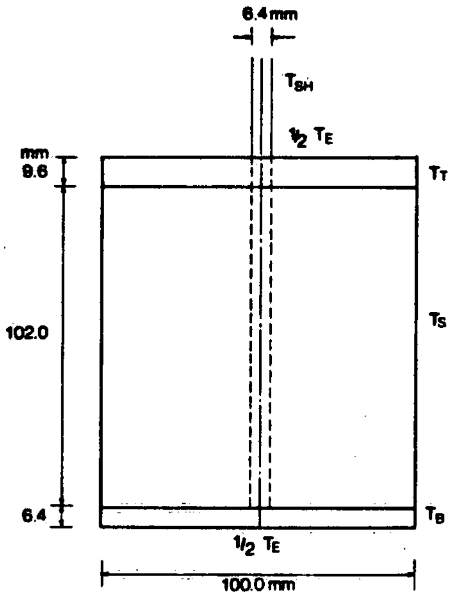


Fig. 4. Torque components for cylindrical sample.

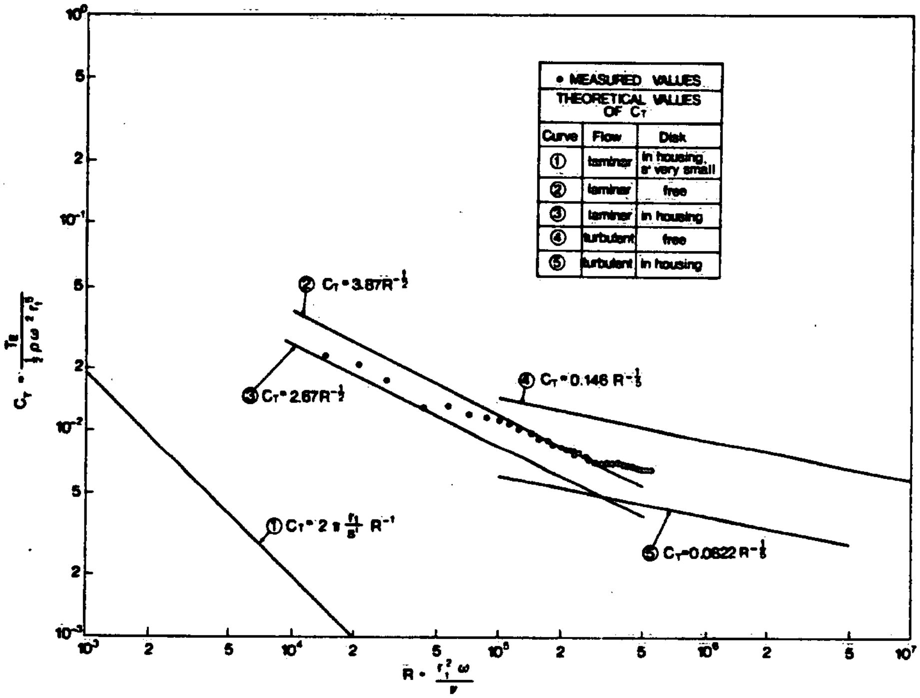
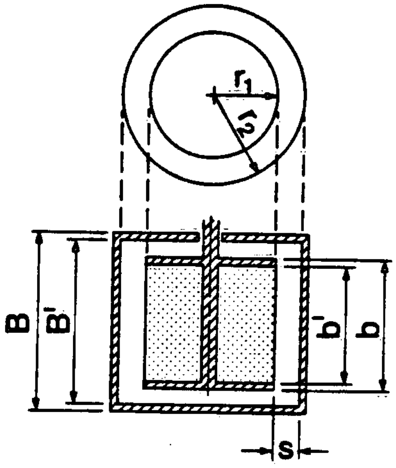


Fig. 5. Measured and theoretical values of dimensionless torque coefficient C_T as a function of Reynolds number R (theoretical relationships after Schlichting, 1968; T_E - torque component acting on end pieces; ρ - density of water; r_1 - radius of cylindrical sample; ω - angular velocity; ν - kinematic viscosity; s' - annular spacing).



r_1 mm	r_2 mm	s mm	b mm	b' mm	B mm	B' mm
50	63	13	118	102	169	150

Fig. 6. Dimensions of rotating transparent cell and calibration aluminum cylinders. Values of b' varied slightly for individual sediment samples.

RESULTS

Analysis of Variance

In order to evaluate the geotechnical and erodibility test results obtained for the three sites, the one-way analysis of variance was applied to test the difference in mean values for each test. The computed F values (where F is the ratio of independent variances estimating the same population variance) are tabulated in Table 2 for Treatment Groups PS-PBA-PBB, PS-PBA & PBB and PBA-PBB. The values marked with an asterisk indicate significant difference at 1% level between sites PS and PB for the silt and clay contents, the liquid limit, the shear strength and the critical shear stress. There is no significant difference in geotechnical and erodibility tests between sites PBA and PBB. Consequently, the data for these two sites are lumped together and average combined values are given in subsequent tables.

Geotechnical Identification Tests

Average values of particle-size analyses are presented in Table 3. According to Shepard's classification (Shepard, 1954), samples collected from Site PS are all silty clays, and the results are in general agreement with previous sampling at this location (Zeman, 1980). Eight samples collected from the waterlain-till stratum at Site PBA are characterized by the absence of sand and gravel, and they are either silty clays or clays. Ten samples collected from site PBB are texturally very similar to the PBA samples, except for a small percentage of sand. They are also either silty clays or clays, except for sample PBB 3, which is sandy silty clay. Data presented in Table 3 show that the PS samples are in general coarser than the PBA and PBB samples.

TABLE 2. ANALYSIS OF VARIANCE (ONE WAY)

Test Type	Treatment Groups PS-PBA-PBB F (2/42)	PS-PBA & PBB F (1/43)	PBA-PBB F (1/16)
Gravel & Sand %	3.07	1.73	1.72
Silt %	11.63*	18.88*	2.00
Clay %	6.46*	13.20*	0.01
Natural Water Content	29.52*	57.08*	0.69
Liquid Limit	6.40*	12.75*	0.11
Plasticity Index	3.84	2.90	2.07
Shear Strength	8.89*	17.08*	0.54
Critical Shear Stress	14.26*	23.95*	1.75
Erosion Rate Gradient	2.75	5.36	1.40

* Significant at 1% level.

TABLE 3. MEAN ($\bar{x}$) AND STANDARD DEVIATION (s) OF PARTICLE-SIZE PERCENTAGES

Site	No. of Samples	Sand and Gravel, %		Silt, %		Clay, %	
		$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
PS	26	5.02	1.58	32.26	4.01	61.50	7.66
PBA	8	0.00	0.00	27.66	9.10	72.34	9.10
PBB	10	5.12	10.87	23.09	4.29	71.81	14.15
PBA & PBB	18	2.84	8.40	25.12	7.02	72.04	11.86

Average values of the natural water content are presented in Table 4. Values obtained for the PS samples are closely scattered around 20%. These values are somewhat higher than the range 16-18% reported by Bou (1975) for this stratigraphic unit. Measurements for the PBA and PBB samples are in the range 26-32% (except for a low value obtained for the relatively coarse Sample PBB 3), and are in general agreement with previous determinations carried out for the waterlain-till unit (Zeman, 1983b).

TABLE 4. MEAN ($\bar{x}$) AND STANDARD DEVIATION (s) OF NATURAL WATER CONTENT

Site	No. of Samples	Nat. Water Content, % $\bar{x}$	s
PS	27	20.79	1.80
PBA	8	28.84	2.73
PBB	10	27.07	5.31
PBA & PBB	18	27.86	4.34

The Atterberg limits tests (Table 5) yielded slightly lower values for the PS samples than for the PBA and PBB samples. The difference is more conspicuous for the liquid limit and the liquidity index than for the plastic limit and the plasticity index. The liquid-limit and plasticity-index values are plotted on the Casagrande plasticity chart (Figure 7), which shows that, except for two anomalous samples, samples from all three sites are clays of low plasticity according to the Unified Soil Classification System (Terzaghi and Peck, 1968).

TABLE 5. MEAN ($\bar{x}$) AND STANDARD DEVIATION (s) OF ATTERBERG LIMITS

Site	No. of Samples	Liquid Limit, %		Plastic Limit, %		Plasticity Index, %		Liquidity Index, %	
		$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
PS	27	31.74	1.39	19.13	1.16	12.62	1.32	0.13	0.12
PBA	8	37.07	1.74	23.25	1.57	13.81	1.83	0.41	0.13
PBB	10	34.99	5.83	19.87	2.39	15.12	3.57	0.45	0.22
PBA & PBB	18	35.92	4.51	21.37	2.65	14.54	2.93	0.43	0.18

Average values of laboratory vane tests are presented in Table 6. The s_{uu} values for the PS samples range from about 42 kPa to 83 kPa, thus being of firm to stiff consistency. All values are

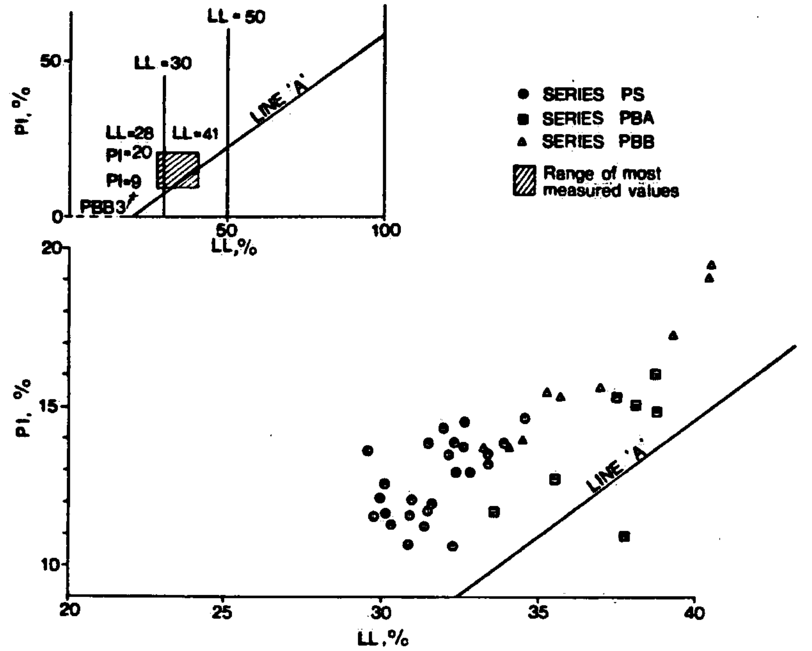


Fig. 7. Results of plasticity tests plotted on the Casagrande chart.

TABLE 6. MEAN ($\bar{x}$) AND STANDARD DEVIATION (s) OF VANE SHEAR STRENGTH

Site	No. of Samples	Undisturbed Shear Strength s_{uu}, kPa $\bar{x}$	s	Remoulded Shear Strength s_{ur}, kPa $\bar{x}$	s	Sensitivity s_{uu}/s_{ur} $\bar{x}$	s
PS	27	55.4	10.8	23.2	4.8	2.4	0.1
PBA	8	36.5	5.7	15.1	2.9	2.5	0.2
PBB	10	41.8	19.7	16.7	7.5	2.5	0.2
PBA & PBB	18	39.5	15.0	16.0	5.8	2.5	0.2

significantly lower than the single value of 268 kPa (2.8 tsf) reported by Bou (1975) for the till at this location. The s_{uu} values measured on the PBA and PBB samples are, except for one sample (PBB 3), of firm consistency within the range 25-46 kPa. The results are in agreement with previous measurements on six samples from this area (Zeman, 1983b). The values of sensitivity, s_{uu}/s_{ur}, are remarkably uniform for all three sites within the range 2.1-3.2, and the average values are given in Table 6.

Erodibility Tests

Results of a representative test are shown in Figure 8 as a shear stress-rpm plot, and in Figure 9 as an erosion rate-shear stress plot. Figure 10 shows variations in the surface roughness during the erodibility test on two representative samples PS 28 and PBB 6.

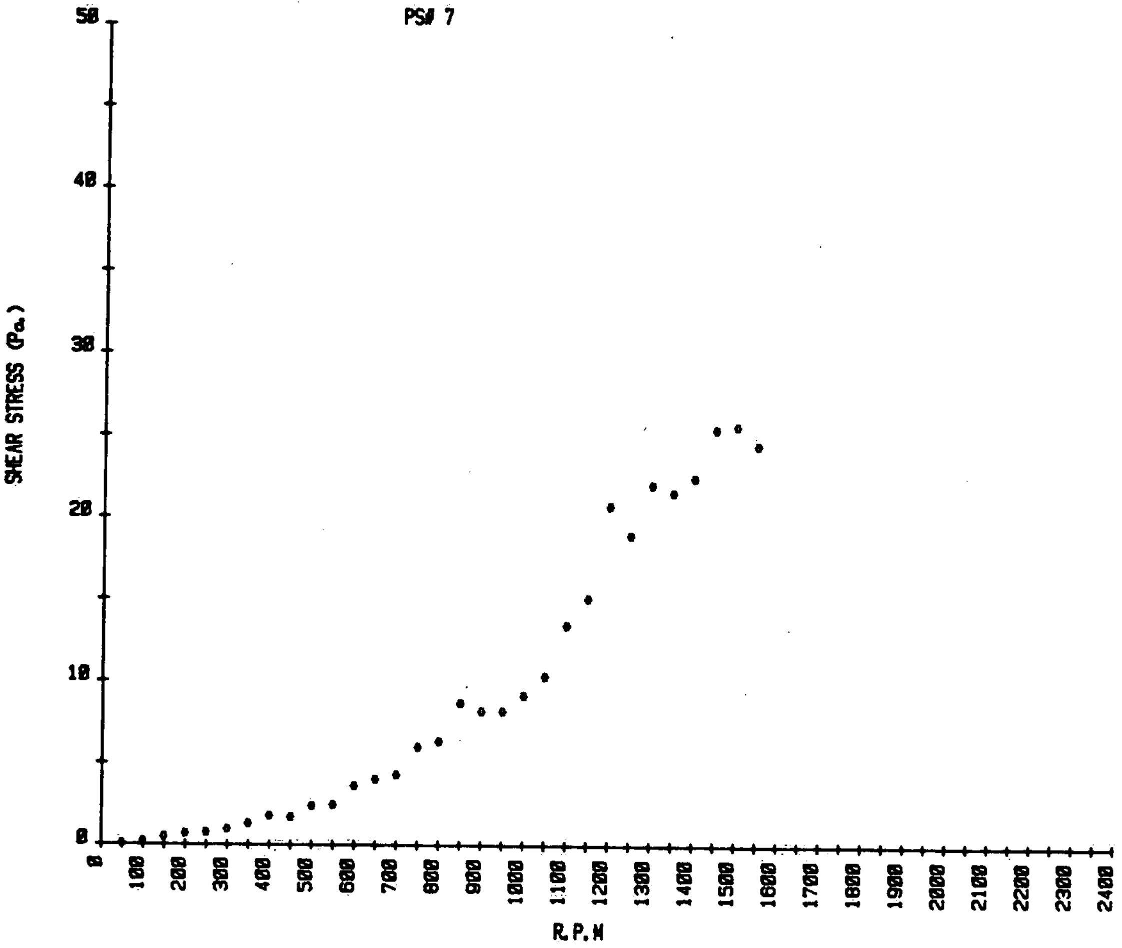


Fig. 8. Representative rpm-shear stress plot (Sample PS 7).

The critical shear stress ranges from 0.68 to 7.05 Pa for Site PS, from 3.06 to 17.66 Pa for Site PBA and from 1.72 to 9.75 Pa for Site PBB; mean and standard deviation values are tabulated in Table 7. The τ_c values are further plotted against the number of revolutions in Figure 11. Both Table 7 and Figure 5 show that, on the average, values for the PBA and PBB samples are higher than those obtained for the PS samples.

As shown in Figure 9, measured erosion rates for individual samples show considerable scatter as a result of changing surface roughness and disintegration of samples along microfissures at higher

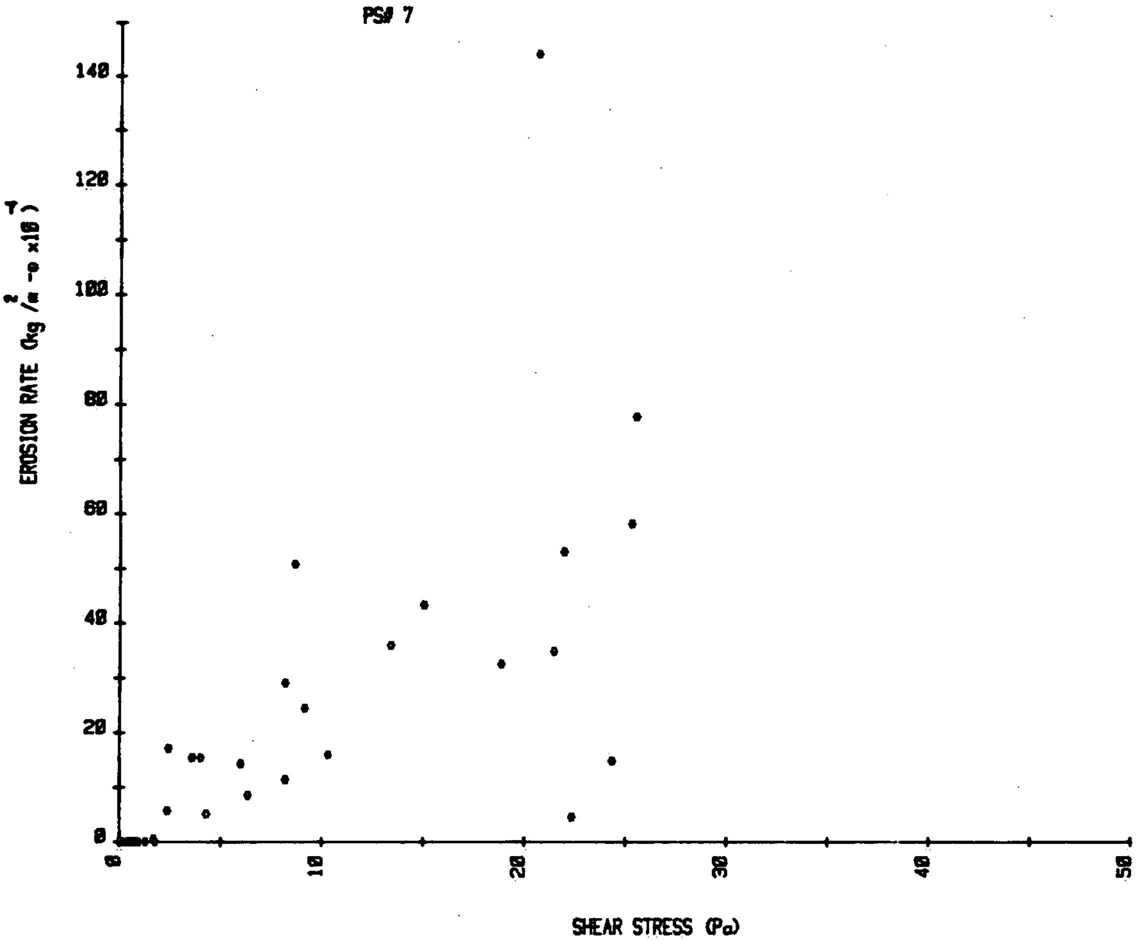


Fig. 9. Representative erosion rate-shear stress plot (Sample PS 7).

shear stresses. Sample erodibility in terms of erosion rates is determined as the slope a_1 of the linear-regression line

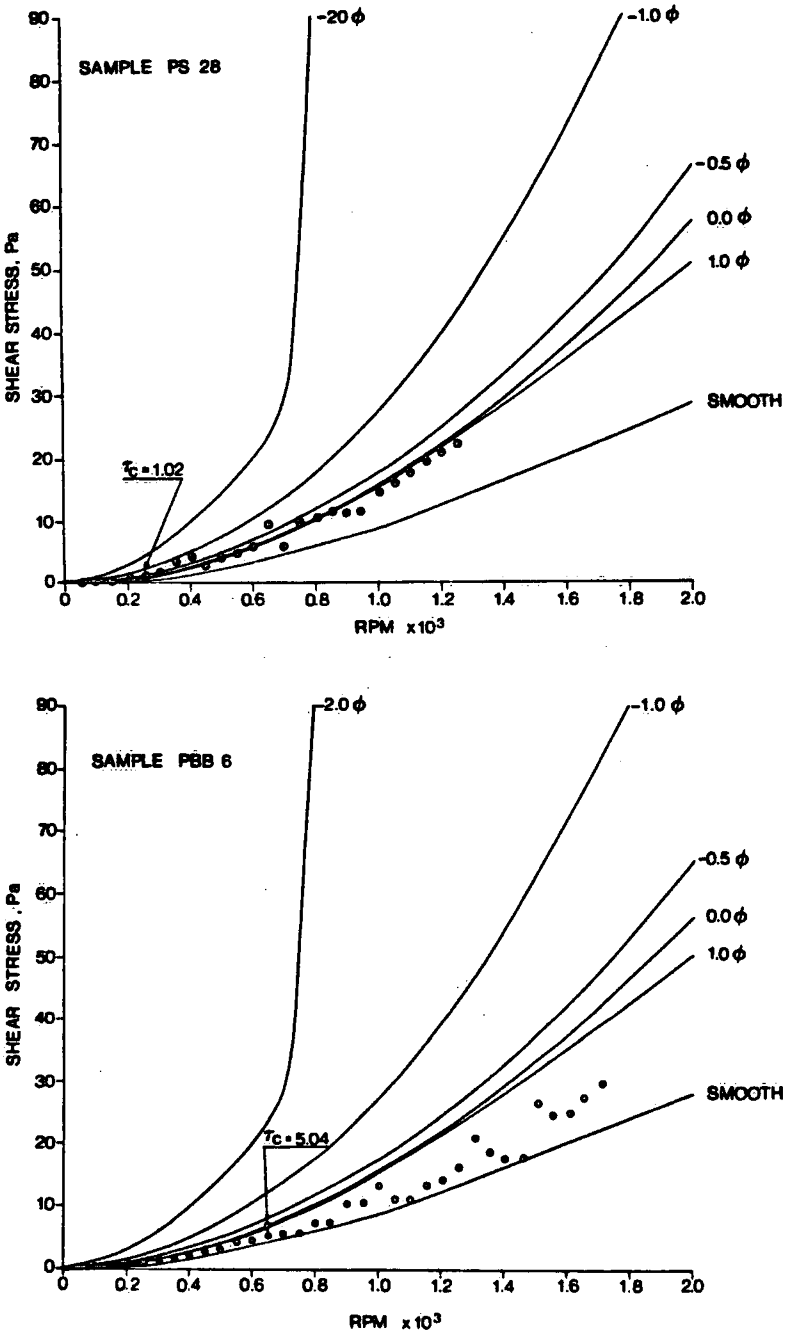
$$\dot{\varepsilon} = a_0 + a_1 \tau \tag{3}$$

Mean and standard deviation values presented in Table 8 indicate that the erosion rate gradient, a_1, is somewhat steeper for the PS samples than for the PBA and PBB samples, however the difference is less conspicuous than in the case of τ_c values, as is also evidenced by relatively low F values for the erosion rate gradient in Table 2.

Another method to present erosion-rate results without the experimental scatter associated with individual samples is to compute the average values of $\dot{\varepsilon}$ and τ for each pre-set value of rpm. These computations have been carried out for the PS samples within the range from 150 to 1300 rpm, and for the PBA and PBB samples within the range from 350 to 1800 rpm. Linear regressions on the averaged data yielded the following relationships

$$\text{Site PS:} \quad \bar{\dot{\varepsilon}} = 0.857 + 0.211\,\bar{\tau} \; ; \; r^2 = 0.73$$

$$\text{Sites PBA \& PBB:} \quad \bar{\dot{\varepsilon}} = -0.371 + 0.097\,\bar{\tau} \; ; \; r^2 = 0.64$$



STANDARD
SURFACE ROUGHNESS

φ	mm
-2.0	4.00
1.0	2.00
0.5	1.41
0.0	1.00
1.0	0.50
SMOOTH	0.00

Fig. 10. Changes in surface roughness during erodibility tests (Samples PS 28 and PBB 6).

TABLE 7. MEAN ($\bar{x}$) AND STANDARD DEVIATION (s) OF CRITICAL SHEAR STRESS

Site	No. of Samples	Critical Shear Stress, Pa $\bar{x}$	Critical Shear Stress, Pa s	Number of Revolutions at Onset of Erosion, rpm $\bar{x}$	Number of Revolutions at Onset of Erosion, rpm s
PS	27	2.00	1.70	361.11	155.25
PBA	8	7.03	4.58	768.75	240.44
PBB	10	4.88	2.16	635.00	158.20
PBA & PBB	18	5.84	3.51	694.44	204.28

TABLE 8. MEAN ($\bar{x}$) AND STANDARD DEVIATION (s) OF EROSION RATE GRADIENT

Site	No. of Samples	Erosion Rate Gradient, a_1* $\bar{x}$	Erosion Rate Gradient, a_1* s	Coefficient of Determination, r^2 $\bar{x}$	Coefficient of Determination, r^2 s
PS	27	0.290	0.281	0.43	0.27
PBA	8	0.100	0.083	0.45	0.22
PBB	10	0.154	0.105	0.35	0.26
PBA & PBB	18	0.130	0.097	0.39	0.24

* determined from linear regression $\dot{\varepsilon} = a_0 + a_1\tau$

The two relationships are plotted in Figure 12 together with the relationship obtained for the Halton Till (Coakley et al., 1986). Figure 12 shows that the waterlain till is less erodible than the Port Stanley till also in term of erosion rates, and that both these tills are less erodible than the Halton Till. This result is consistent with the values of average τ_c obtained for the three tills.

Comparison of Geotechnical and Erodibility Tests

Linear regressions have been performed on results of geotechnical and erodibility tests (Table 9). As shown in individual tables, (Tables 3 to 6) geotechnical properties measured vary within relatively narrow ranges. When data obtained for the PS and PBA & PBB samples were analyzed separately, values of the correlation coefficient, r, were not significant, apart from the regressions PL-τ_c (Table 9). Upon combining the data for the three sites, significant relations at the 1% level were obtained for w-τ_c, LL-τ_c, PL-τ_c, LI-τ_c and s_{uu}-τ_c. The first four relations are direct; the remaining one is

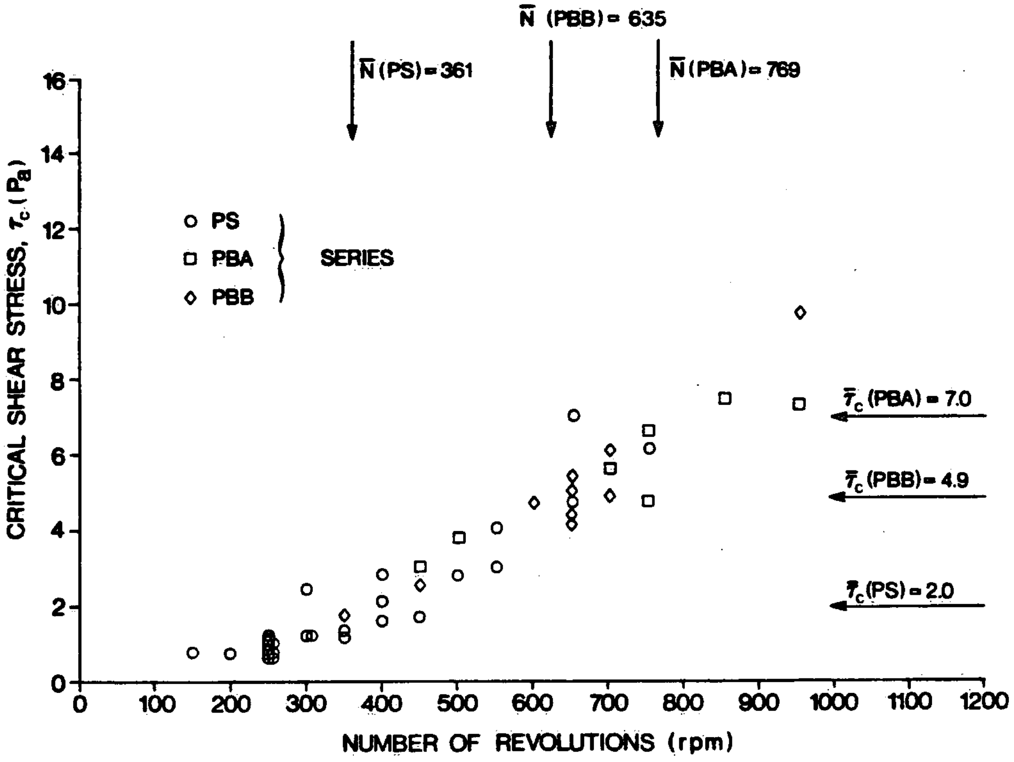


Fig. 11. Critical shear stress values for all samples as a function of N (number of revolutions).

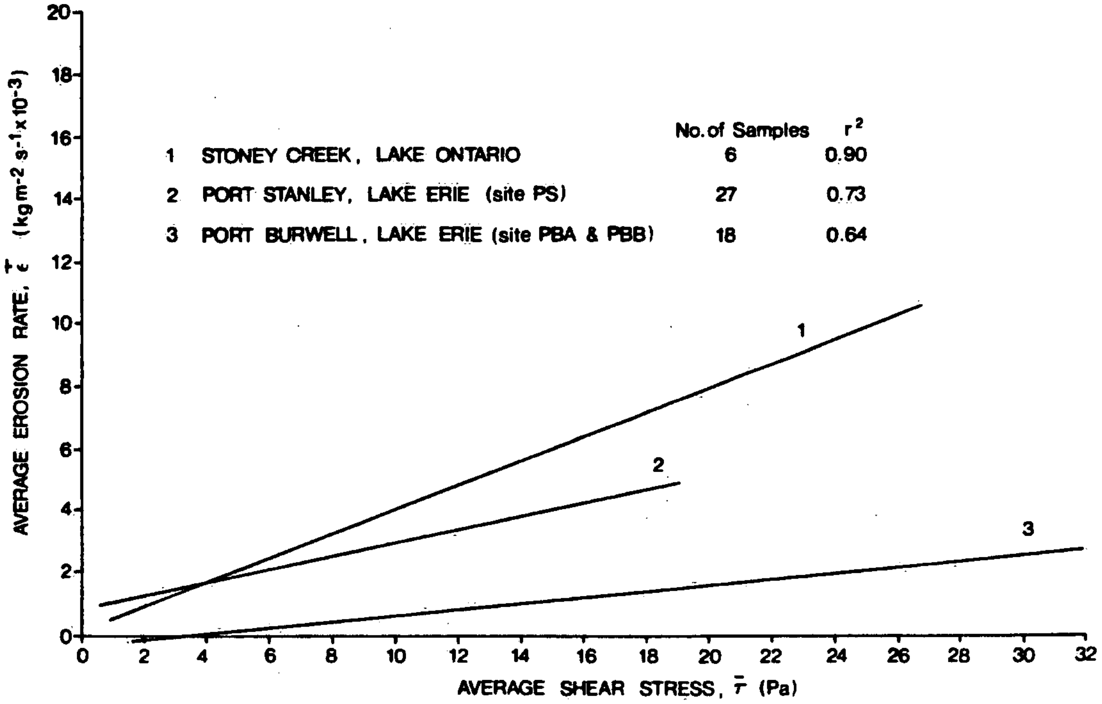


Fig. 12. Averaged relationships between $\dot{\varepsilon}$ and τ for Site PS and Sites PB. Relationship for the Halton Till (Coakley et al., 1986) is also shown for comparison.

inverse. The direct relation cl%-τ_c and the inverse relation si%-τ_c were found to be significant at the 5% level. The comparison of geotechnical test results with the erosion rate gradient, a_1, yielded no statistically significant values of r.

TABLE 9. SIGNIFICANT VALUES OF (r) FOR LINEAR REGRESSIONS BETWEEN GEOTECHNICAL AND ERODIBILITY PARAMETERS

Site(s)	Regression*	Significance at 5% Level	Significance at 1% Level
PS	PL - τ_c	r = 0.42	
PBA & PBB	PL - τ_c		r = 0.61
PS & PBA & PBB	cl% - τ_c	r = 0.36	
	si% - τ_c	r = 0.30	
	w - τ_c		r = 0.59
	LL - τ_c		r = 0.46
	PL - τ_c		r = 0.55
	LI - τ_c		r = 0.54
	s_{uu} - τ_c		r = 0.41

* symbols: cl% = clay content, si% - silt content, w = natural water content, LL = liquid limit, PL = plastic limit, LI = liquidity index, s_{uu} = vane shear strength, τ_c = critical shear stress

DISCUSSION

The tests described in this paper have been deliberately conducted on undisturbed samples. Most studies concerned with erosion resistance of cohesive sediments described in the literarature have been carried out on artificially-compacted samples, which do not include the effect of the natural structure of the sediment.

Quantitative determination of erodibility with a rotating-cylinder apparatus has both its advantages and limitations. The principal advantage is that the testing procedure is relatively rapid and therefore a large number of samples can be tested within a reasonable length of time. This aspect of the testing method is an important one because of significant differences in erosion resistance encountered during tests on sediments from the same location. This is particularly true for the determination of erosion rates as a function of applied shear stress. Another advantage is that the shear stress applied to the sediment surface can be directly computed from torque measurements and does not have to be derived from measurements of fluid velocity. Furthermore, significantly higher shear stresses can be generated than in flume tests. As to the limitations of the rotating-cylinder test, it is not possible to study the effect of sand abrasion, which is known to be of fundamental importance (Kamphuis, 1983). The testing method does not permit testing of samples that are too soft or that have very low cohesion. Testing of samples under the conditions of oscillatory flow is not possible at present without a major modification of the apparatus. In spite of these shortcomings, test results are considered to be encouraging as they provide answers which are quite conclusive and which would not be probably obtained otherwise.

CONCLUSIONS

The principal findings of the study can be summarized as follows:

1. A new quantitative method for measurement of sediment erodibility has been developed that permits testing of undisturbed cohesive tills. The method is relatively rapid and yields consistent test results.

2. Forty-five samples from three sites and two till formations on the Lake Erie north shore were collected. The two tills differ, at statistically significant levels, in several geotechnical properties (si%, cl%, w, LL and s_{uu}) and in values of τ_c. No differences of this type were obtained for samples from the two sites within the same till formation.

3. The critical shear stress values of the Port Stanley Till are significantly lower than those obtained for the waterlain till. Average erosion rates for the Port Stanley Till are also higher than those measured for the waterlain till. Both Lake Erie tills are less erodible than the Halton Till from Lake Ontario.

4. The critical shear stress values correlate reasonably well with several geotechnical properties (w, LL, PL, LI, s_{uu}). Relations between the erosion rate gradient and geotechnical properties are not statistically significant.

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