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Reproducibility of Sieve and Settling Tube Textural Determinations for Sand-sized Beach Sediment

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ABSTRACT

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Using 525 beach sediment samples, the reproducibility of sieve and settling tube textural determinations is examined, in order to assess the suitability of both methods for determining parameters for use in environment of deposition or sediment transport models. Agreement between classifications of settling tube and sieve determinations of textural parameters is poor, with 37%, 44% and 77% of replicates having different mean grain size, sorting and skewness classifications respectively. The mass of the sediment sub-sample used affects textural parameters derived by both settling tube and sieve analyses. Mean grain size determined by settling tube increases with increasing sub-sample mass, whereas the mean grain size derived by sieving shows no trend. Sorting deteriorates (more poorly sorted) with increasing sub-sample mass for settling tube analyses, but improves slightly (better sorted) for sieve analyses. Skewness tends to become more finely skewed with increasing sub-sample mass for sub-sample masses less than 50 g, for both methods. The variability of settling tube results is least for sub-sample masses of 20–30 g. These results indicate that settling tube textural parameters must be used with caution in any environmental or transport numerical model based on sediment textural characteristics, at least for beach sands of the type used here. In particular, settling tube determined textural parameters cannot be directly substituted into a model derived from sieve analyses. Models based solely on specific numeric ranges of 1 or 2 textural parameters should be avoided. Models based on trends are more likely to result in reproducible interpretations.

ADDITIONAL INDEX WORDS: *Mean grain size, skewness, sorting, depositional environments, sediment transport.*

INTRODUCTION

In many sedimentological investigations, the sediment size distribution is of major importance, since it reflects the nature of the source rocks or materials and the resistance of the particles to the process of weathering, erosion, transportation and deposition. Although doubts have been expressed about the value of sediment textural data for interpreting environments of deposition or sediment transport behaviour (viz. ERLICH, 1983; MCMANUS, 1988), models based on measured sediment textures were and are being developed for the interpretation of sedimentary environments (viz. FOLK and WARD, 1957; FRIEDMAN, 1961, 1967; BLATT *et al.,* 1980; MIDDLETON, 1976), and transport mechanisms or directions (viz. SUNAMURA and HORIKAWA, 1972; COMBELLICK and OSBORNE, 1977; SELF, 1977; MCLAREN, 1981). Most models are based on observations of sediment texture derived from sieve analyses of predominantly sand-sized sediment. However, the development of settling tube systems, particularly in conjunction with automated methods of data collection and analysis has led to a decline in sieving analyses (DYER, 1986). As a consequence during sedimentological investigations it may be necessary to: 1) compare the results of a settling tube textural analysis with earlier results for the same site determined by sieving; and 2) use settling tube textural data in an environmental or transport interpretative model derived from sieving observations. This raises the questions of the relationship between settling tube and sieve grain sizes and the reproducibility of settling tube results. The interpretation of sediment texture in terms of environment of deposition or sediment transport behaviour often relies upon small differences between samples. If the inherent variability of the method of analysis exceeds these differences, such interpretation is invalid. Previous comparisons between textural determinations made by sieve and settling tube analysis have considered either single grains or very low concentration monomineralic suspensions (viz. BABA and KOMAR, 1981; KOMAR and CUI, 1984). However, textural determinations usually involved mixed mineralogy samples and moderate to high concentration suspensions. Although it is obvious that sieve and settling tube analyses actually measure different physical properties and are therefore likely to show considerable variation due to the varying proportions of mineralogical components, the need to compare and utilise textural data derived by both methods is an ongoing one. Therefore, the aims of this paper are to: 1) compare the textural parameters predicted by sieve and settling tube analyses of the

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same mixed mineralogy samples; and 2) investigate the reproducibility of results obtained by settling tube analyses, and in particular to examine the influence of sample mass on reproducibility.

THE RAPID SEDIMENT ANALYSER (RSA) SYSTEM

The University of Waikato RSA system was developed in 1983 to permit faster processing of sand-sized sediment samples and to provide a more realistic measure of the hydraulic behaviour of sediments with a wide range of shapes and densities found on New Zealand beaches (HEALY *et al.,* 1983). This system operates semi-automatically with a settling tube, but also can process size data measured by sieving, pipette and hydrometer analyses.

The settling tube consists of 2 nested Lexan tubes: the outer is 0.27 m in diameter and provides a thermal jacket to minimise temperature fluctuations in the inner tube, as well as additional structural strength; and the inner is 0.20 m in diameter. The total length of the tubes is 2.00 m, although the effective settling distance is normally 1.80–1.90 m. Samples are introduced via a sample holder fitted with horizontally sliding jaws. A relay is closed when the jaws are opened, which is detected by the computer. The sample submerged mass is measured by a pan suspended from an electronic balance at the top of the tubes.

The rest of the system comprises a software package written at the University of Waikato, originally for Apple II series computers, but now based on the Macintosh series. Once the sample has been released, the mass of the pan is recorded at 1 Hz for a pre-set period, commonly 900 sec. Analyses can also be terminated when a specified size or settling velocity class has been measured or when the sample weight does not vary by more than a specified error limit within a defined time interval.

After data collection has finished, the RSA uses cumulative mass and measurement time to determine the settling velocity and size distribution. Settling velocities are processed in terms of the Chi (χ) parameter proposed by MAY (1981) using the method of moments to derive mean, sorting, skewness and kurtosis parameters. The settling velocities are converted to hydraulic equivalent sphere sizes using the GIBBS *et al.* (1971) equation, with sediment density and fluid property corrections as determined by KOMAR (1981). The RSA version used for this study did not apply the settling velocity corrections of BABA and KOMAR (1981) or the sieve corrections of KOMAR and CUI (1984).

The RSA software may also be connected to a balance used for recording the cumulative weights in a sieve analysis. The sieves used are defined by the operator before weighing, and the system then records the cumulative mass after each sieve is added to the balance. Alternatively, measured data may be entered manually or via a text file. When size data comprising size class boundaries and cumulative mass have been obtained, the RSA undertakes a size distribution analysis using both the FOLK and WARD (1957) graphical method and the method of moments.

METHODS

Surficial sediment samples were collected from 15 beaches along the eastern Coromandel and Bay of Plenty coastlines of New Zealand (DARLAN, 1991). Samples of ~2 kg were collected from either the crest of the foredune, the face of the most recent berm, or the beach face. The samples consisted entirely of medium to coarse sand; mainly comprising quartz, feldspars and volcanic glass, with minor quantities of carbonate (shell material), heavy minerals (mainly titanomagnetite) and rock fragments.

All samples were wet sieved on 0.063 mm sieves to remove any minor proportions of silts, clays and precipitated salts, and then dried at 120 °C. Any gravel-sized materials were retained. Each sample was split into 35 sub-samples (comprising 5 each of 10, 20, 30, 40, 50, 70 and 100 g masses), giving a total of 525 sub-samples analysed. The sub-samples first underwent a sieve analysis and were retained for a subsequent settling tube analysis (DARLAN, 1991). This procedure was followed to ensure that the sample analysed by the settling tube had exactly the same characteristics as that determined by the sieve analysis, despite any destruction of clasts by the sieving process.

The sieve analysis was undertaken on a Fritsch electromechanical shaker using US standard 0.20 m diameter brass sieves at ¼ phi intervals between −1 and 4 phi. All sub-samples were shaken for 15 minutes. The settling tube was operated for 15 minutes, which corresponds to the same size range, and measurements were taken at time corresponding to ¼ phi intervals (DARLAN, 1991). The data obtained by both methods were subsequently processed by the Rapid Sediment Analyser (RSA) system discussed above.

The mean grain size, sorting and skewness parameters as determined by the graphical method of FOLK and WARD (1957) were selected for subsequent statistical analysis, because they appear most often in models for environment of deposition or transport mechanism or direction (MCMANUS, 1988). The size parameters were then analysed using DataDesk Professional V3.0, a statistical package available on Macintosh computers. The analyses included: 1) two-way ANOVA test without interactions; 2) comparison of descriptive textural classifications, specifically the classification of FRIEDMAN and SANDERS (1978) for mean grain size, FOLK (1968) classification for sorting, and FOLK (1968) skewness classification; and 3) determination of any trends and reproducibility of each parameter, with respect to sub-sample mass and sample site.

ANALYSIS AND RESULTS

ANOVA Analyses

The textural parameters obtained were first subjected to two-way ANOVA tests without interactions. The dependent variables were mean grain size, sorting and skewness, and the treatments were site, environment of deposition, mass of sub-sample used, and method of analysis. The null hypotheses were taken to be that individual treatments had no effect on the textural parameter. This should be the case for the site treatment and the environment treatment, if the envi-

Table 1. *Summary of results for two way ANOVA analyses without interactions on (A) the entire data set; (B) size distributions obtained by sieving; and (C) size distributions obtained by settling tube analysis. (df = degrees of freedom; probability = probability of a Type I error; SITE = sample site; ENVIRON = environment of deposition; MASS = mass of sub-sample; and METHOD = method of analysis).*

Parameter	Source	df	F Ratio	Probability
(A) Entire data set (n = 1,050)				
Mean	SITE	14	2,035.9	0.00
	ENVIRON	2	3,196.1	0.00
	MASS	6	50.3	0.00
	METHOD	1	4,783.5	0.00
Sorting	SITE	14	287.1	0.00
	ENVIRON	2	0.0	1.00
	MASS	6	34.1	0.00
	METHOD	1	276.3	0.00
Skewness	SITE	14	41.7	0.00
	ENVIRON	2	0.0	1.00
	MASS	6	9.26	0.00
	METHOD	1	1,836.7	0.00
(B) Sieve (n = 525)				
Mean	SITE	14	16,176.0	0.00
	ENVIRON	2	0.0	1.00
	MASS	6	0.92	0.48
Sorting	SITE	14	2,808.7	0.00
	ENVIRON	2	0.0	1.00
	MASS	6	5.73	0.00
Skewness	SITE	14	250.7	0.00
	ENVIRON	2	0.0	1.00
	MASS	6	5.62	0.00
(C) Settling tube (n = 525)				
Mean	SITE	14	1,702.5	0.00
	ENVIRON	2	0.0	1.00
	MASS	6	183.2	0.00
Sorting	SITE	14	144.3	0.00
	ENVIRON	2	0.0	1.00
	MASS	6	150.7	0.00
Skewness	SITE	14	7.30	0.00
	ENVIRON	2	0.0	1.00
	MASS	6	15.3	0.00

ronments are sufficiently distinct since this is one of the underlying assumptions inherent in interpretative models based on sediment size distributions.

At the 99% significance level ($\alpha = 0.01$), the null hypotheses are rejected for most combinations of textural parameters and treatments (Table 1A). However, both the sorting and the skewness parameters display no difference between the samples analysed with respect to the environment of deposition. This implies that sorting and skewness are not dependent on the environment of deposition, whereas mean grain size is. For the other treatments, the implication is that sample site, method of analysis and mass of sub-sample used are having a systematic effect on the size distribution.

The data were split into 2 groups consisting of sieve analyses and settling tube analyses, and two-way ANOVA analyses repeated with site, environment of deposition and mass treatments (Table 1B and C). The null hypothesis was accepted ($\alpha = 0.01$) in all cases involving the environment of deposition. Therefore, the rejection in the case of the mean grain size noted above is probably a reflection of the difference in mean grain size obtained by the two methods and not an indication of the discrimination of environments by mean grain size. Thus, although 3 environments of deposition were identified in the field, there is a statistical difference between the grain size distributions for the samples analysed.

This may have been due to the fact that only one set of beach face data were included in the analysis. The data for beach and berm face environments were combined into one category of beach environment and the tests repeated. The null hypothesis was still accepted for all cases involving environment of deposition. The null hypothesis was rejected ($\alpha = 0.01$) for all other cases, except the case involving mass treatment and mean size as determined by sieve analysis. This implies that the mean grain size of samples determined by sieve analysis is not affected by the mass of the sub-sample used. Apart from this exception, size parameters are affected by site and sub-sample mass.

Mean Grain Size

Agreement between sieve and settling tube classifications is not good (Figure 1 and Table 2), with 37% of the paired replicates classifying differently. Whereas all replicates of a given sample returned the same size classification by sieving, the results predicted by the settling tube analysis varied with increasing sample mass. The closest agreement between sieve and settling tube predicted size classifications occurred for samples of 10 g mass, and the worst for samples of 100 g mass. Regression analyses were undertaken to compare the mean grain size as determined by sieving with that determined by the settling tube. A linear regression combining all the sub-samples produced the following equation with a regression coefficient (r^2) of 0.933 (n = 525):

$$\text{Sieve mean (phi)} = 0.06 + 1.16 \text{ Settling tube mean (phi)} \qquad (1)$$

Therefore, the sieve size distributions have a finer mean grain size than that indicated by settling tube distributions (Figure 1), which agrees with the findings of BABA and KOMAR (1981) and KOMAR and CUI (1984). Since ANOVA analyses and Figure 1 indicate that the mean grain size determined by the settling tube varies with the mass of the sub-sample used, separate regressions were also performed for each replicate group of sub-sample masses. The resulting equations were statistically different ($\alpha = 0.01$), but were fairly similar to Equation 1 and confirmed that the sieved distributions suggest a finer mean grain size than obtained from settling tube distributions.

Although linear fits to the data are reasonably good, Figure 1 shows that the deviation between settling tube and sieve mean grain size increases with decreasing grain diameter (increasing phi value). Therefore the true relationship for the data analysed is non-linear. The clustering evident in Figure 1 is partly due to the influence of sample site, with the different environments of deposition being randomly spread. Accordingly the data were examined more closely as individual data sets for each site. Settling tube analyses had a consistent trend of increasing mean grain diameter with increasing mass of sample analysed, whereas sieved replicates showed no significant change, as indicated by the deviation apparent in Figure 1.

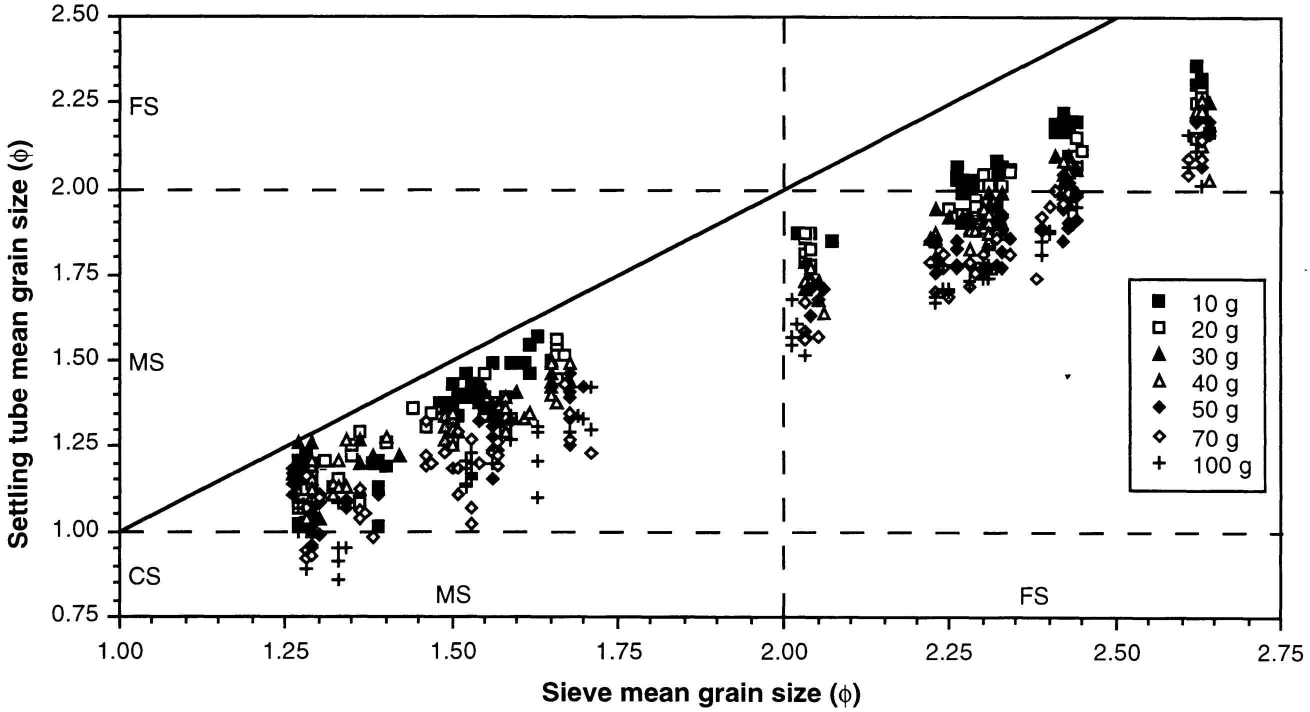

Figure 1. Settling tube mean grain size versus sieve mean grain size for replicate sub-samples. The clustering evident is partially a function of the environment of deposition, but is primarily a function of sample site. The size classification follows that of Friedman and Sanders (1978) where: (CS) coarse sand; (MS) medium sand; and (FS) fine sand. The solid diagonal line indicates exact correspondence (settling tube mean grain size = sieve mean grain size).

Table 2. *Occurrences of* Friedman *and* Sanders *(1978) size classifications for the mean grain size by (A) sieving and (B) settling tube analysis. CS = coarse sand; MS = medium sand; FS = fine sand.*

	Environment											
	Dune Crest			Berm Face			Beach Face			Total		
Mass (g)	CS	MS	FS	CS	MS	FS	CS	MS	FS	CS	MS	FS
A) Seive												
10		15	20		15	20		5			35	40
20		15	20		15	20		5			35	40
30		15	20		15	20		5			35	40
40		15	20		15	20		5			35	40
50		15	20		15	20		5			35	40
70		15	20		15	20		5			35	40
100		15	20		15	20		5			35	40
Total		105	140		105	140		35			245	280
B) Settling tube												
10		17	18		20	15		5			42	33
20		24	11		25	10		5			54	21
30		30	5		25	10		5			60	15
40		33	2		25	10		5			63	12
50	1	33	1		26	9		5		1	64	10
70	3	31	1	1	29	5	2	3		6	63	6
100	3	32		4	26	5		5		7	63	5
Total	7	200	38	5	176	65	2	33		14	309	102

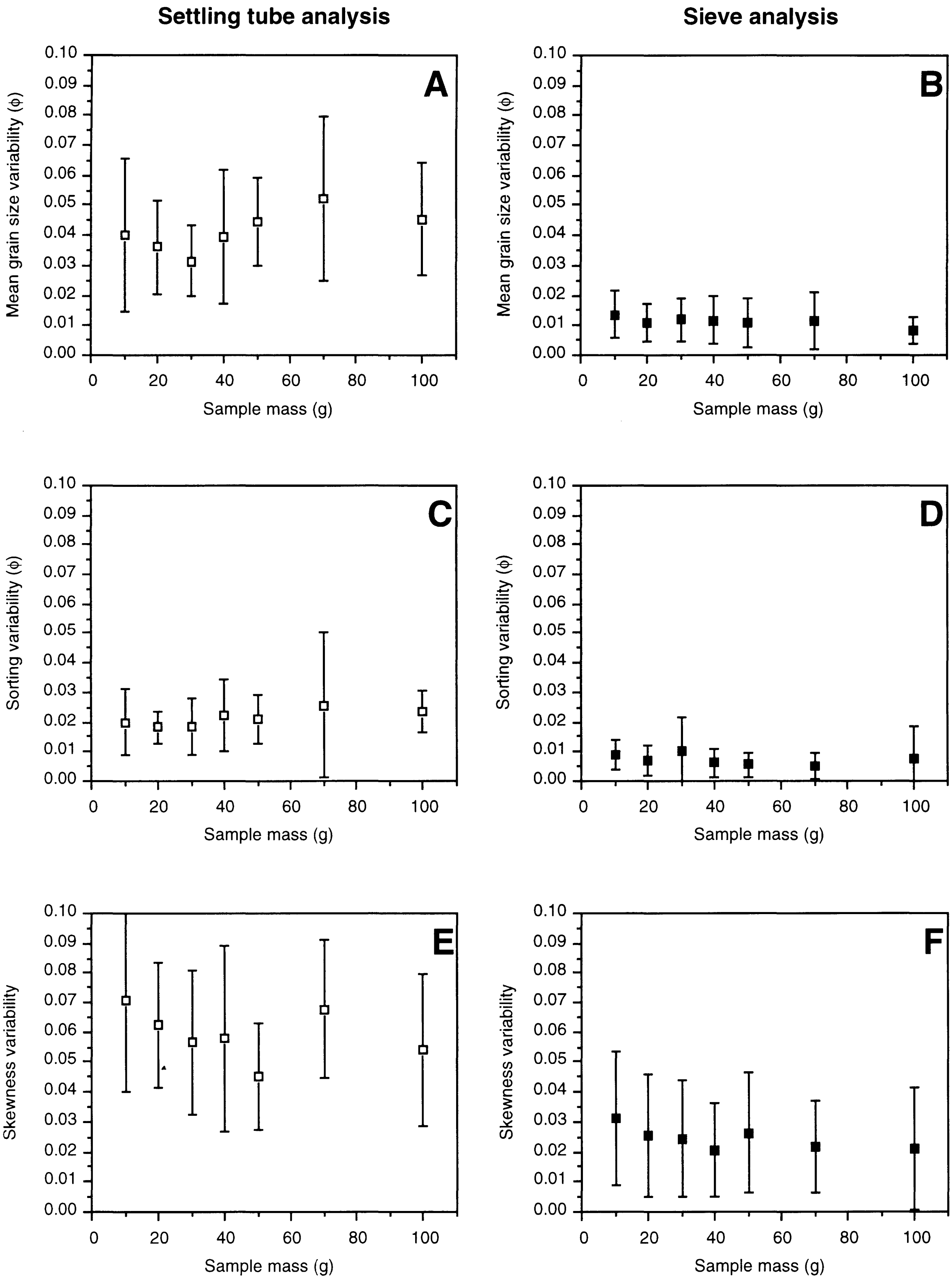

Figure 2. Comparison of the variability of each textural parameter considered for both settling tube and sieve textural determinations (A) settling tube mean grain size; (B) sieve mean grain size; (C) settling tube sorting; (D) sieve sorting; (E) settling tube skewness; (F) sieve skewness. Plotted data consist of the mean deviations of 5 replicates for each beach. The error bars correspond to ± σ.

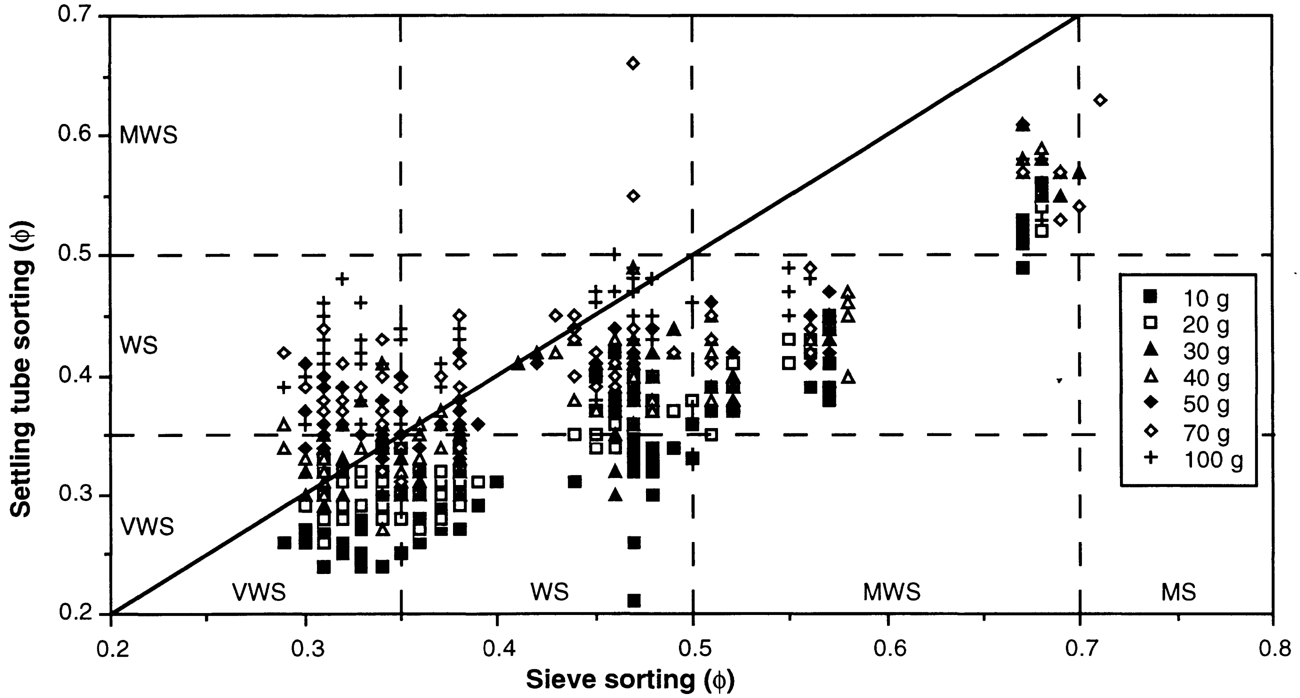

Figure 3. Settling tube sorting versus sieve sorting for replicate sub-samples. The sorting classification is after FOLK (1968), where: (MS) moderately sorted; (MWS) moderately well sorted; (WS) well sorted; and (VWS) very well sorted. The solid diagonal line indicates exact correspondence (settling tube sorting = sieve sorting).

Overall, sieve analysis determinations resulted in a lower variability (expressed as the mean deviations for each sub-sample) than the settling tube analyses (Figure 2A and B). In all cases, the variation was less than ±0.1 phi. No significant trend is evident with increasing sub-sample mass for settling tube variability. However, the minimum variability occurs for 30 g sub-samples.

Sorting

With respect to sorting, 44% of the paired replicates classify differently, with the settling tube analysis generally predicting a better sorted class than the sieve analysis (Figure 3 and Table 3). Sorting predicted by settling tube analyses becomes more poorly sorted (increases in value); whereas, sorting determined from sieve data becomes better sorted (decreasing value), with increasing sub-sample mass. The closest agreement between the two methods occurs for samples of 40 g mass. The dependence of sorting determined from settling tube size distributions with increasing sub-sample mass is attributed to increased turbulence during settling. This increases entrainment of individual grains and clumps of grains by the wakes of larger particles. This acts to broaden peaks in the sediment size distribution as sediment is displaced into coarser size classes, resulting in increased sorting values (more poorly sorted) and a coarser mean grain size.

The variability of sorting parameters was consistently less than for the other textural parameters considered (Figure 2C and D). The minimum variability of sorting determined by settling tube occurs for 20 g sub-samples.

Skewness

Agreement between the skewness classification predicted by both methods is extremely poor, with 77% of the paired replicates classifying differently. In most cases, the settling tube predicted a more positive (finer) skewness than the sieve analysis (Figure 4). Both methods display a tendency towards more positive (finer) skewness as sub-sample mass increases from 10 g to 40 g. At higher masses, no clear trend is apparent. Overall, settling tube data indicate predominantly positive (fine) skewness, whereas sieve data were mainly negatively (coarse) skewed (Figure 4). No mass replicate showed consistently good agreement between the two methods. DYER (1986) and McMANUS (1988) note that the thickness of sediment on each sieve may affect the size distribution. An initial thickness greater than 4–6 grain diameters tends to result in the sieve apertures being clogged by grains only slightly larger than the holes. This will limit the passage of finer grain sizes through the size, distorting the distribution towards coarse or negative skewness; this is the opposite of the observed trend.

The variability of skewness was greater than the other textural parameters considered (Figures 2E and F). For settling tube determinations of skewness, the least variability occurred for samples of 50 g mass.

Table 3. *Occurrences of* Folk *(1968) range classifications for the sorting parameters determined by (A) sieving and (B) settling tube analysis. VWS = very well sorted; WS = well sorted; MWS = moderately well sorted; MS = moderately sorted.*

	Environment													
	Dune Crest			Berm Face				Beach Face			Total			
Mass (g)	VWS	WS	MWS	VWS	WS	MWS	MS	VWS	WS	MWS	VWS	WS	MWS	MS
A) Sieve														
10	14	16	5	6	20	9			5		20	41	14	
20	12	18	5	9	16	10			4	1	21	38	16	
30	11	19	5	6	20	8	1		5		17	44	13	1
40	13	17	5	10	15	10			5		23	37	15	
50	17	13	5	10	15	10			5		27	33	15	
70	12	18	5	10	15	8	2		5		22	38	13	2
100	15	15	5	10	16	9			5		25	36	14	
Total	94	116	35	61	117	64	3		34	1	155	267	100	3
B) Settling tube														
10	28	7		22	9	4		5			55	16	4	
20	25	10		16	14	5			5		41	29	5	
30	21	14		13	17	5			5		34	36	5	
40	14	21		9	21	5			5		23	47	5	
50	8	27		2	28	5			5		10	60	5	
70	3	32		1	29	5			3	2	4	64	7	
100		35			30	5			5			70	5	
Total	99	146		63	148	34		5	28	2	167	322	36	

DISCUSSION AND SUMMARY

A number of different approaches for environmental and transport interpretation have been attempted. The simplest is to map the spatial distribution of one or more textural parameters, which permits systematic trends to be recognised. However, it has been recognised that there are covariations of 2 or more textural parameters which may be hydraulically controlled. Therefore, there have been many attempts to characterise environments of deposition with bivariate or multivariate models.

The simplest models determine environments from textural classifications of only 1 or 2 textural parameters. Other models define envelopes of numerical values, usually in the form of scattergrams (McManus, 1988), which encompass particular depositional environments, using various combinations of 2 or more textural parameters. Models for interpretation of sediment transport usually rely on spatial trends, such as methods for determining transport direction based on trends of mean grain size, sorting or skewness.

Some of these approaches are sensitive to the variability of settling tube data and the discrepancies between sieve and settling tube results. The worst variability of settling tube results encountered is less than ±0.1 phi for mean grain size and sorting, and about ±0.1 for skewness. Hence the variability of settling tube results can be considered to be low, provided that samples of equal mass are compared. If samples of different mass are used, then variability is increased due to the mass dependence of the size distribution. Although the variability of numerical size parameters for the data considered is small, the corresponding textural classifications are not as consistent, particularly at higher moments. Class boundaries for size, sorting, and skewness classifications are not equally spaced, but become increasingly closer together for higher moments, so that the spacing for mean grain size classes is 1.00 phi, for sorting classes varies from 2.00 to 0.15 phi, and for skewness classes is 0.20. Thus, in terms of classifying the sediment texture, the variability is more significant for higher moment parameters.

If samples are analysed by different methods the variability is increased due to the discrepancies between sieve and settling tube distributions. The variation in textural classifications between techniques is even greater. Normally, maps of textural parameters are smoothed by contouring so that variations smaller than the contour interval should not affect the outcome. However, if the sediment textural data were not obtained by the same technique or inconsistent sample masses were used, the variation may exceed any useful contouring interval. From the foregoing, it is evident that models for interpretation of environment of deposition based on textural classifications should only be used for data derived by the same method as the model. Even so, it is possible that model results may be unreliable, particularly for sediments close to textural class boundaries. Models based on numerical envelopes with separations greater than 0.1 should not be affected by the variability of the settling tube method, provided the models were derived from settling tube data and consistent sample masses used. However, the fact that it was not possible to statistically discriminate the 3 environments used in this study suggests that this type of approach may not be useful for similar environments of deposition.

Provided consistent sample sizes are used for all analyses, models based on textural trends are likely to produce reproducible interpretations. Such methods are less dependent on the actual values of textural parameters and are therefore less affected by the variations discussed above.

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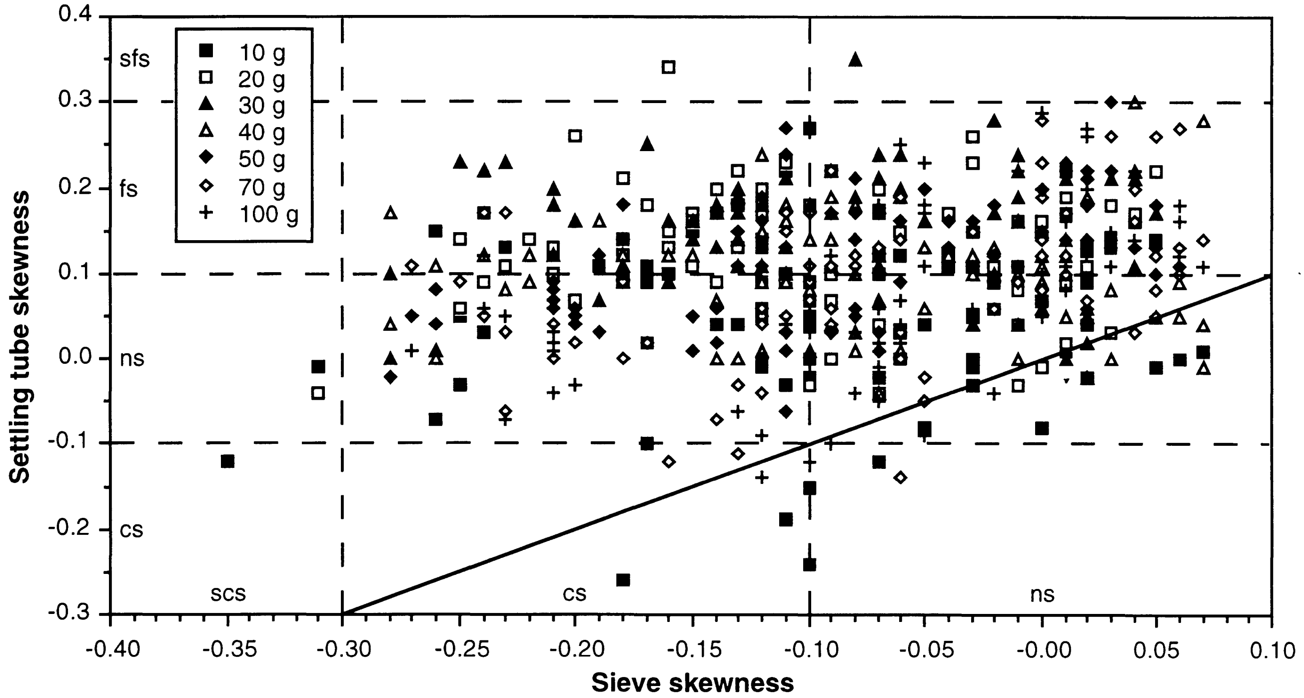

Figure 4. Settling tube skewness versus sieve skewness for replicate sub-samples. The skewness classification is that of Folk (1968), where: (scs) strongly coarse skewed; (cs) coarse skewed; (ns) near symmetrical; (fs) fine skewed; and (sfs) strongly fine skewed. The solid diagonal line indicates exact correspondence (settling tube skewness = sieve skewness).

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