APPENDIX I

Sediment Transport Model

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1 SEDIMENT TRANSPORT MODEL

The following is a brief review of the sediment transport model, a detailed analysis of which is contained in McLaren and Bowles (1985). The required information used throughout this analysis is the grain-size distribution which, for the purpose of Sediment Trend Analysis, is defined for any size class as the probability of the sediment being found in that size class. Size classes are defined in terms of the well-known ϕ (phi) unit, where d is the effective diameter of the grain in millimeters.

$$\mathrm{d(mm)} = 2^{-\phi}\ ;\ \text{or}\ \log_2 \mathrm{d(mm)} = -\phi$$

Given that the grain-size distribution $g(s)$, where s is the grain size in phi units, is a probablility distribution, then

$$\int_{-\infty}^{\infty} g(s)ds = 1$$

In practice, grain-size distributions do not extend over the full range of s, and are not continuous functions of s. Instead we work with discretized versions of $g(s)$ with estimates of $g(s)$ in finite sized bins of 0.5ϕ width.

Three parameters related to the first 3 central moments of the grain-size distribution are of fundamental importance in Sediment Trend Analysis. They are defined here, both for a continuous $g(s)$ and for its discretized approximation with N size classes. The first parameter is the mean grain size (μ), defined as:

$$\mu = \int_{-\infty}^{\infty} s \cdot g(s)ds \approx \sum_{i=1}^{N} s_i \cdot g(s_i)$$

The second parameter is sorting (σ) which is equivalent to the variance of the distribution, defined as:

$$\sigma^2 = \int_{-\infty}^{\infty} (s-\mu)^2 \cdot g(s)ds \approx \sum_{i=1}^{N} (s_i-\mu)^2 \cdot g(s_i)$$

Finally, the coefficient of skewness (κ) is defined as:

$$\kappa = \frac{1}{\sigma^3} \int_{-\infty}^{\infty} (s-\mu)^3 \cdot g(s)ds \approx \frac{1}{\sigma^3} \sum_{i=1}^{N} (s_i-\mu)^3 \cdot g(s_i)$$

1.1 Case A (Development of a lag deposit)

Consider a sedimentary deposit that has a grain-size distribution *g(s)* (Figure AI- 1). If eroded, the sediment that goes into transport has a new distribution, *r(s)*, which is derived from *g(s)* according to the function *t(s)* so that:

$$r(s_i) = k \cdot g(s_i) t(s_i)$$

$$\text{or} \quad t(s_i) = \frac{r(s_i)}{k \cdot g(s_i)}$$

where $g(s_i)$ and $r(s_i)$ define the proportion of the sediment in the i[th] grain-size class interval for each of the sediment distributions. '*k*' is a scaling factor[1] that normalizes *r(s)* so that:

$$\sum_{i=1}^{N} r(s_i) = 1$$

$$\text{thus} \quad k = \frac{1}{\sum_{i=1}^{N} g(s_i) t(s_i)}$$

With the removal of *r(s)* from *g(s)*, the remaining sediment (a lag) has a new distribution denoted by *l(s)* (Figure AI- 1) where:

$$l(s_i) = k \cdot g(s_i)[1 - t(s_i)]$$

$$\text{or} \quad t'(s_i) = \frac{l(s_i)}{k \cdot g(s_i)}$$

$$\text{where} \quad t'(s_i) = 1 - t(s_i)$$

The function *t(s)* is defined as a sediment transfer function and is described in exactly the same manner as a grain-size probability function except that it is not normalized. It may be thought of as a function that incorporates all sedimentary and dynamic processes that result in initial movement and transport of particular grain sizes.

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[1] 'k' is actually more complex than a simple normalizing function, and its derivation and meaning is the subject of further research. It appears to take into account the masses of sediment in the source and in transport, and may be related to the relative strength of the transporting process.

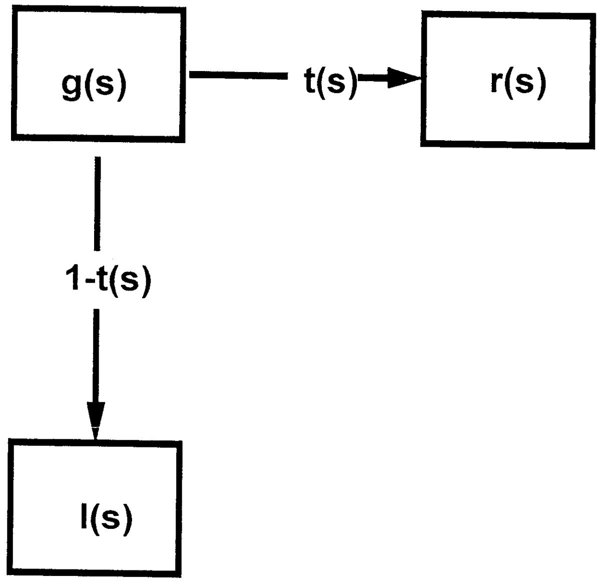


Figure AI- 1: Sediment transport model to develop a lag deposit (see the text for a definition of terms).

Data from flume experiments show that distributions of transfer functions change from having a high negative skewness to being nearly symmetrical (although still negatively skewed) as the energy of the eroding/transporting process increases. These two extremes in the shape of *t(s)* are termed low energy and high energy transfer functions respectively (Figure AI- 2). The shape of *t(s)* is also dependent, not only on changing energy levels of the process involved in erosion and transport, but also on the initial distribution of the original bed material, *g(s)*(Figure AI- 1). The coarser *g(s)* is, the less likely it is to be acted upon by a high energy transfer function. Conversely, the finer *g(s)* is, the easier it becomes for a high energy transfer function to operate on it. In other words, the same process may be represented by a high energy transfer function when acting on fine sediments, and by a low energy transfer function when acting on coarse sediments. The terms high and low energy are, therefore, relative to the distribution of *g(s)* rather than to the actual process responsible for erosion and transport.

The fact that *t(s)* appears to be mainly a negatively skewed function results in *r(s)*, the sediment in transport, always becoming finer and more negatively skewed than *g(s)*. The function *1-t(s)* (Figure AI- 1) is, therefore, positively skewed, with the result that *l(s)*, the lag remaining after *r(s)* has been removed, will always be coarser and more positively skewed than the original source sediment.

If *t(s)* is applied to *g(s)* many times (i.e., *n* times, where *n* is large), then the variance of both *g(s)* and *l(s)* will approach zero (i.e., sorting will become better). Depending on the initial distribution of *g(s)*, it is mathematically possible for variance to become greater before eventually decreasing. In reality, an increase in variance in the direction of transport is rarely observed.

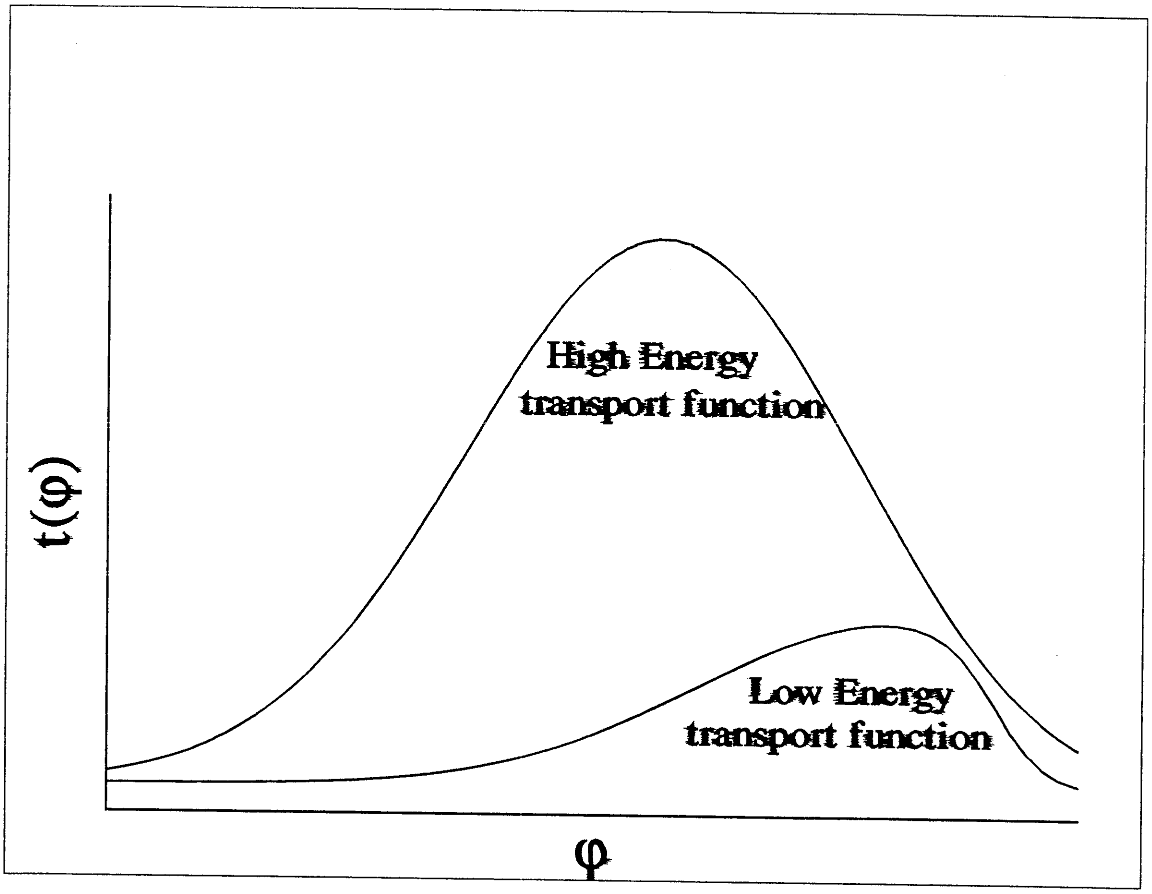


Figure AI- 2: Diagram showing the extremes in the shape of transfer functions t(φ).

Given two sediments whose distributions are, $d_1(s)$ and $d_2(s)$, and $d_2(s)$ is coarser, better sorted and more positively skewed than $d_1(s)$, it may be possible to conclude that $d_2(s)$ is a lag of $d_1(s)$ and that the two distributions were originally the same (Case A; Table AI- 1).

1.2 1.2 Case B (Sediments becoming finer in the direction of transport)

Consider a sequence of deposits ($d_1(s)$, $d_2(s)$, $d_3(s)$,...) that follows the direction of net sediment transport (Figure AI- 3). Each deposit is derived from its corresponding sediment in transport according to the "3-box model" shown in Figure AI- 1. Each $d_n(s)$ can be considered a lag of each $r_n(s)$. Thus, $d_n(s)$ will be coarser, better sorted and more positively skewed than $r_n(s)$. Similarly, each $r_n(s)$ is acted upon by its corresponding $t_n(s)$ with the result that the sediment in transport becomes progressively finer, better sorted and more negatively skewed. Any two sequential deposits (e.g., $d_1(s)$ and $d_2(s)$) may be related to each other by a function $X(s)$ so that:

$$d_s(s) = k \cdot d_1(s) \cdot X(s)$$

$$\text{or } X(s) = \frac{d_2(s)}{k \cdot d_1(s)}$$

$$\text{where } k = \frac{1}{\sum_{i=1}^{N} d_1(s_i) \cdot X(s_i)}$$

As illustrated in Figure AI- 3, $d_2(s)$ can also be related to $d_1(s)$ by:

$$d_2(s) = \frac{k \cdot d_1(s) t_1(s)[1 - t_2(s)]}{1 - t_1(s)}$$

$$= k \cdot d_1(s) X(s) \qquad (1)$$

where $$X(s) = \frac{t_1(s)[1 - t_2(s)]}{1 - t_1(s)} \qquad (2)$$

The function $X(s)$ combines the effects of two transfer functions $t_1(s)$ and $t_2(s)$ (Equation 2). It may also be considered as a transfer function in that it provides the statistical relationship between the two deposits and it incorporates all of the processes responsible for sediment erosion, transport and deposition. The distribution of the deposit $d_2(s)$ will, therefore, change relative to $d_1(s)$ according to the shape of $X(s)$ which, in turn, is derived from the combination of $t_1(s)$ and $t_2(s)$ as expressed in Equation 2. It is important to note that $X(s)$ can be derived from the distributions of the deposits $d_1(s)$ and $d_2(s)$ (Equation 1) and it provides the relative probability of any particular sized grain being eroded from d_1, transported and deposited at d_2.

Using empirically derived $t(s)$ functions, it can be shown that when the energy level of the transporting process decreases in the direction of transport (i.e., $t_2(s_i) < t_1(s_i)$) and both are low energy functions (Figure AI- 4), then $X(s)$ is always a negatively skewed distribution. This will result in $d_2(s)$ becoming finer, better sorted and more negatively skewed than $d_1(s)$. Therefore, given two sediments (d_1 and d_2) where $d_2(s)$ is finer, better sorted and more negatively skewed than $d_1(s)$, it may be possible to conclude that the direction of sediment transport is from d_1 to d_2 (Table AI- 1).

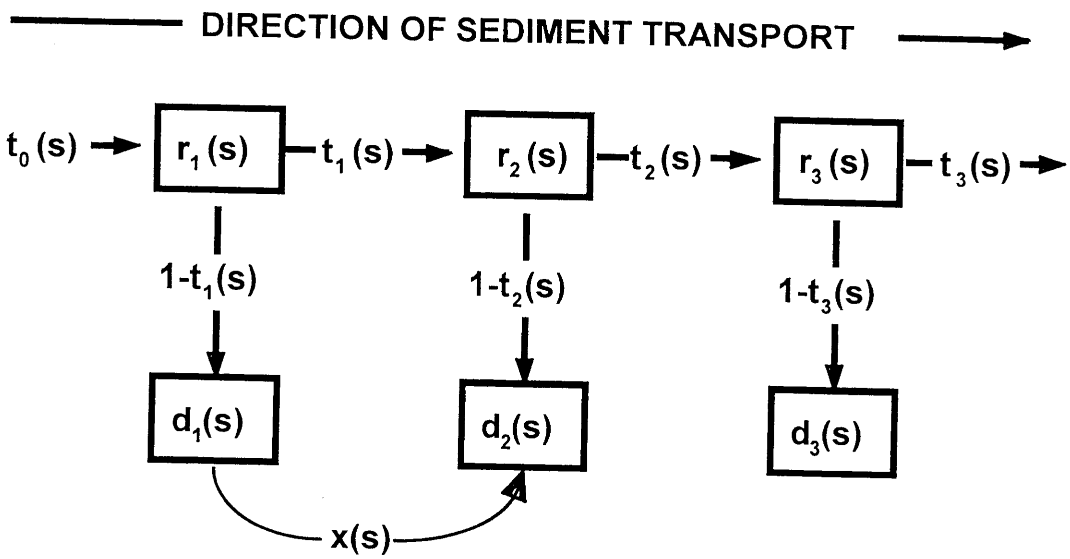


Figure AI- 3: Sediment transport model relating deposits in the direction of transport (see Appendix I for definition of terms).

1.3 1.3 Case C (Sediments becoming coarser in the direction of transport)

In the event that $t_1(s)$ is a high energy function (Figure AI- 2) and $t_2(s_i) < t_1(s_i)$ (i.e., energy is decreasing in the direction of transport), the result of Equation 2 will produce a positively skewed $X(s)$ distribution. Therefore, $d_2(s)$ will become coarser, better sorted and more positively skewed than $d_1(s)$ in the direction of transport (Figure AI- 4). When these changes occur between two deposits, it may be possible to conclude that the direction of transport is from d_1 to d_2 (Table AI- 1).

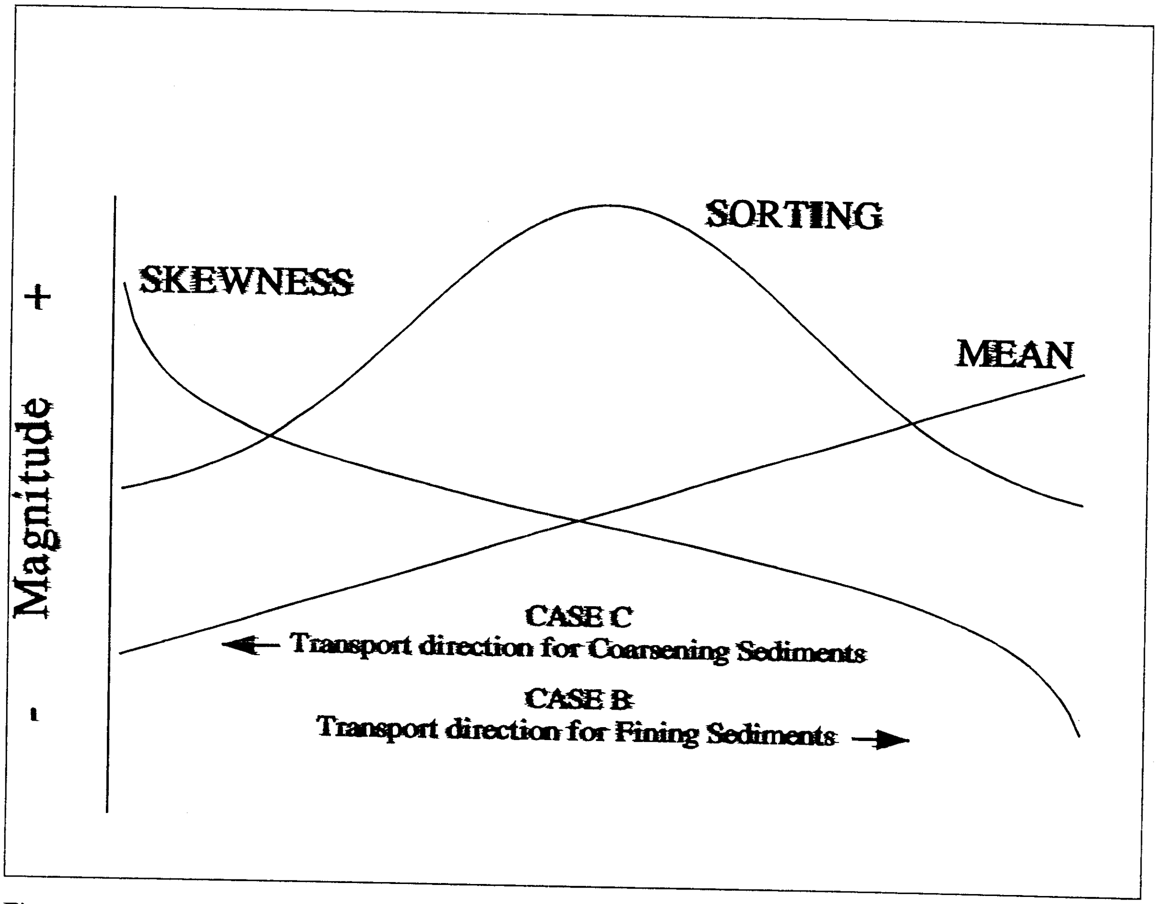


Figure AI- 4: Changes in grain-size descriptors along transport paths.

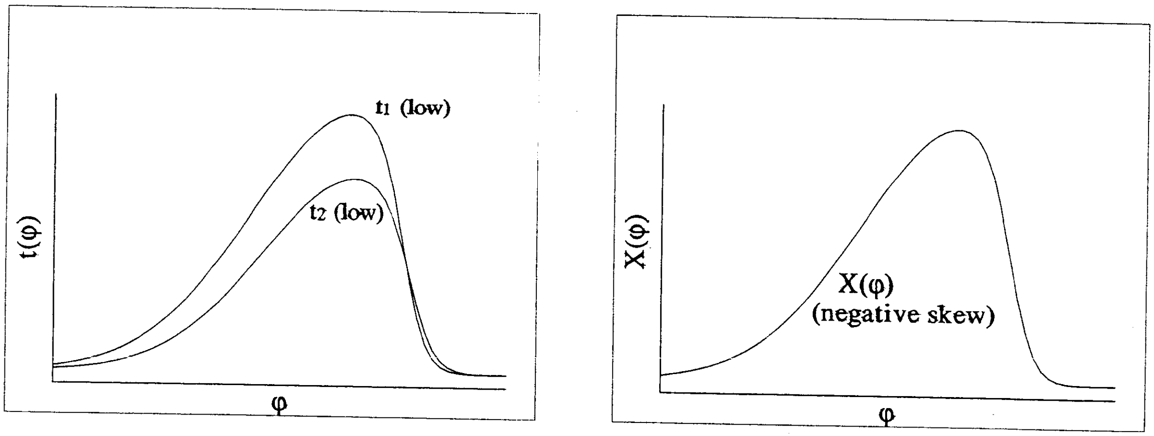
Table AI- 1: Summary of the interpretations with respect to sediment transport trends when one deposit is compared to another.

CASE	RELATIVE CHANGE IN GRAIN-SIZE DISTRIBUTION BETWEEN DEPOSIT d_2 AND DEPOSIT d_1	INTERPRETATION
A	Coarser Better sorted More positively skewed	d_2 is a lag of d_1. No direction of transport can be determined.
B	Finer Better sorted More negatively skewed	(i) The direction of transport is from d_1 to d_2. (ii) The energy regime is decreasing in the direction of transport. (iii) t_1 and t_2 are low energy transfer functions.
C	Coarser Better sorted More positively skewed	(i) The direction of transport is from d_1 to d_2. (ii) The energy regime is decreasing in the direction of transport. (iii) t_1 is a high energy transfer function and t_2 is a high or low energy transfer function (Figure AI- 5).

Sediment coarsening along a transport path will be limited by the ability of $t_1(s)$ to remain a high energy function. As the deposits become coarser, it will be less and less likely that the transport processes will maintain high energy characteristics. With coarsening, the transfer function will eventually revert to its low energy shape (Figure AI- 2) with the result that the sediment must become finer again.

Cases A and C produce identical grain-size changes between d_1 and d_2 (Table AI- 1). Generally, however, the geological interpretation of the environments being sampled will differentiate between the two Cases.

CASE B: $t_2 < t_1$; both low energy functions



CASE C: $t_2 < t_1$; t_1 is a high energy function; t_2 is high or low.

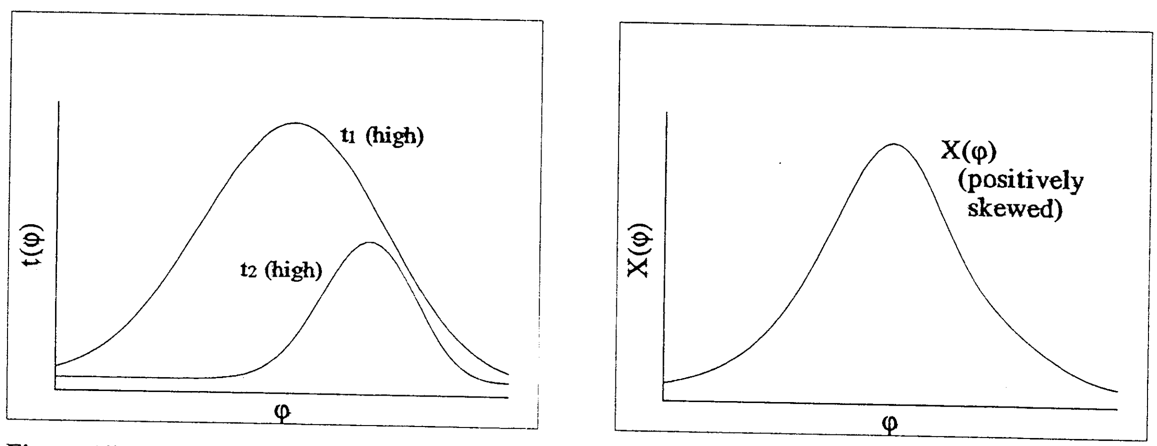


Figure AI- 5: Summary diagram of t_1 and t_2 and corresponding X-distribution (Equation 2) for Cases B and C (Table AI- 1).

2 METHOD TO DETERMINE TRANSPORT DIRECTION FROM GRAIN-SIZE DISTRIBUTIONS (SEDIMENT TREND ANALYSIS)

2.1 Uncertainties

The above model indicates that grain-size distributions will change in the direction of transport according to either Case B or Case C[2] (Table AI- 1; Figure AI- 4). Thus, if any

[2] Case A which defines the development of a lag deposit is not used to determine a sediment transport direction. There may be instances when a Case C transport direction is determined which, in fact, is not Case C transport, but rather Case A. For example, in some Arctic environments, sediments become progressively coarser, better sorted and more positively skewed from deep to shallow water. It is impossible to suppose that there is a high energy transport fumction operating on the deep water sediments resulting in Case C transport towards the shoreline. In this enviroment, ice action and currents result in the winnowing of the finer size fractions as the water shallows. Thus Case A indicating the development of a lag is the accepted Case, rather than Case C. As stated earlier, a geological interpretation may be required to differentiate between the development of a lag (Case A) and a genuine transport pathway (Case C).

two samples (d_1 and d_2) are compared sequentially (i.e., at two locations within a sedimentary facies), and their distributions are found to change in the described manner, the direction of net sediment transport may be inferred.

A Sediment Trend Analysis attempts to determine the patterns of net sediment transport over an area through the grain-size distributions of the sediments. The sampled sediments are described in statistical terms (by the moment measures of mean, sorting and skewness) and the basic underlying assumption is that processes causing sediment transport will affect the statistics of the sediments in a predictable way. Following from this assumption, the size frequency distributions of the sediments provide the data with which to search for patterns of net sediment transport.

In reality, perfect sequential changes along a transport path as determined by the model are rarely observed. This is because of a variety of uncertainties that may be introduced in sampling, in the analytical technique to obtain grain-size distributions, in the assumptions of the transport model, and in the statistics used in describing the grain-size distributions. These uncertainties may be summarized as follows:

(1) The use of the log-normal distribution:

Although sediments are typically described by a particle weight distribution based on the log of the grain-size (i.e., the phi scale where particle diameter in mm = $2^{-\phi}$) there is, in fact, no way to determine the "best" descriptor for all sediments. The log-normal distribution has been found useful in practice since it appears to highlight important features of naturally occurring sediments. Bias can, however, be introduced in the choice of distribution. For example, the mean of the distribution in phi space is not equal to the mean of the distribution in linear space. Using the moment measures (mean, variance and skewness) may highlight important features and suppress those that are unimportant; however, information will also be lost. There is no way to determine if the lost information is significant (Bowles and McLaren, 1985).

Whatever method is used to describe the sediments, the trend analysis requires the above model which demonstrates that transport processes will change the moment measures of sediments in a predictable way. It is hoped that future research may be able to address the possible benefits of using other distributions (e.g., the log hyperbolic distribution; Hartmann and Christiansen, 1992).

(2) Assumptions in the transport model:

In providing a mathematical proof for the transport model used in the Sediment Trend Analysis (McLaren and Bowles, 1985), a basic assumption is made that smaller grains are more easily transported than larger grains. As seen in the transfer functions obtained from flume experiments (Fig. AI-2), this assumption is not strictly true. The curves monotonically increase over only a portion of the available grain sizes before returning to zero. Factors such as shielding whereby the presence of larger grains may impede the transport of smaller grains, or the decreasing ability of the eroding process to carry additional fines with increasing load, demonstrate that the transport process is a complicated function related to the sediment distribution and the strength of the erosion process.

(3) Temporal fluctuations:

Sediment samples may comprise the effects of several transport processes. It is assumed that what is sampled is the "average" of all the transport processes affecting the sample site. The "average" transport process may not conform to the transport model developed for a single transport process.

In a Sediment Trend Analysis, it is assumed that a sample provides a representation of a specific sediment type (or facies). There is no direct time connotation, nor does the depth to which the sample was taken contain any significance provided that the sample does, in fact, accurately represent the facies. For example d_1 may be a sample of a facies that represents an accumulation over several tidal cycles, and d_2 represents several years of deposition. The trend analysis simply provides the sedimentological relationship between the two (see McLaren, 1981 for a more detailed discussion of sampling). The possibility also exists that different samples may result from a different suite of transport events.

(4) Sample spacing:

Sample sites may be too far apart to detect relevant transport processes. With increasing distance between sample locations there is an increasing possibility of collecting sediments unrelated by transport (i.e., different facies). Sample sites placed X m apart can only be reliable to detect transport processes with a spatial scale of 2X m or more. Transport processes with smaller spatial scales may appear as noise or spurious signals.

In practice, selection of a suitable sample spacing takes into account: (1) the number of sedimentological environments likely to be encountered; (2) the desired spatial scale of the sediment trends; and (3) the geographic shape of the study area (see below for further discussion of sample spacing).

(5) Random environmental uncertainties:

All samples will be affected by random errors. These may include unpredictable fluctuations in the depositional environment, the effects of sampling and sub-sampling a representative sediment population, and random measurement errors.

2.2 The use of the Z-score statistic

Given the above list of complicating factors that introduce uncertainties in establishing the net patterns of transport, it is rare to find sequences of samples whose distributions change exactly according to Figure AI- 4. One approach that appears to be successful in determining trends is a simple statistical method whereby the Case (Table AI- 1) is determined among all possible sample pairs contained in a specified sequence. Given a sequence of n samples, there are $\frac{n^2 - n}{2}$ directionally orientated pairs that may exhibit a transport trend in one direction, and an equal number of pairs in the opposite direction. When any two samples are compared with respect to their distributions, the mean may become finer (F) or coarser (C), the sorting may become better (B) or poorer (P), and the skewness may become more positive (+) or more negative (-). These three parameters provide 8 possible combinations (Table AI- 2).

Table AI- 2: All possible combinations of grain-size parameters

	1*	**2**	**3**	**4**
Mean Sorting Skewness	F B -	C B -	F P -	F B +
	5	**6**	**7****	**8**
Mean Sorting Skewness	C P +	F P +	C B +	C P -

* Case B (Table AI- 1)
** Case A or C (Table AI- 1)

In Sediment Trend Analysis we postulate that a certain relationship exists among the set of n samples, and that this relationship is evidenced by particular changes in sediment size descriptors between pairs of samples. Then the number of pairs for which the trend relationship occurs should exceed the number of pairs that would be expected to occur at random by a sufficient amount for us to state confidently that the trend relationship exists. Suppose the probability of any trend existing between any pair of samples, if the trend relationships were established randomly, is p. Since there are 8 possible trend relationships among 3 sediment descriptors, and we assume that each of these is equally likely to occur, the value of p is set at 0.125.

To determine if the number of occurrences that a particular Case exceeds the random probability of 0.125, the following two hypotheses are tested:

H_0: $p<0.125$, and there is no preferred direction; and
H_1: $p>0.125$, and transport is occurring in the preferred direction.

Using the Z-score statistic in a one-tailed test (Spiegel, 1961), H_1 is accepted if:

$$Z = \frac{x - Np}{\sqrt{Nqp}} \rangle 1.645 \quad \text{(0.05 level of significance)}$$

$$\text{or} \qquad \rangle 2.33 \quad \text{(0.01 level of significance)}$$

where x is the observed number of pairs representing a particular Case in one of the two opposing directions; and N is the total number of possible unidirectional pairs, given by $\frac{n^2-n}{2}$. The number of samples in the sequence is n; p is 0.125; and q is $1.0 - p = 0.875$.

The Z statistic is considered valid for N>30 (i.e., a large sample). Thus, for this application, a suite of 8 or 9 samples is the minimum required to evaluate adequately a transport direction.

3 DERIVATION OF SEDIMENT TRANSPORT PATHWAYS

From the above it is seen that a variety of uncertainties may preclude obtaining a "perfect" sequence of progressive changes in grain-size distributions from sediment samples that follow a specific transport pathway (Figure AI- 4). In using the Z-score statistic, however, a transport trend may be determined whereby all possible pairs in a sample sequence are compared with each other. When either a Case B or Case C trend exceeds random probability within the chosen sample sequence, the direction of net sediment transport can be inferred. In using the Z-score statistic, a minimum of 9 samples should be used which indicates that, if transport pathways are to be determined over a specific area, a minimum grid of 9 by 9 samples is required (i.e., 81 samples). As suggested above, the grid spacing must be compatible with the area under study and take into account the number of sedimentological environments likely to be involved, the geographic shape of the study area, and the desired statistical certainty of the pathways. For practical purposes, it has been found that, for regional studies in open ocean environments, sample spacing should not exceed 1 km; in estuaries spacing should be reduced to 500 m. For site specific studies (e.g., to determine the transport regime for a single marina), sample spacing will be reduced so that a minimum number of samples can be taken to ensure an adequate coverage (i.e., 9 X 9 samples). Experience has also shown that extra samples should be taken over sites of specific interest (e.g., dredged material disposal sites) and, should the regular grid be insufficient, from specific bathymetric features (e.g., bars and channels).

In determining transport patterns over an area, it is useful to draw an analogy with communication systems. In the latter, information is transmitted to a distant location where a signal is received containing both the desired information as well as noise. The receiver must extract the information from the noisy signal. In theory, the information can be recovered by simply subtracting the noise from the signal, an approach that works well in communications systems because the nature of both the information and the noise is well known.

In sedimentary systems, the information is the direction of net sediment transport, and the received signal is the grain-size distributions of the sediment samples. The goal of a Sediment Trend Analysis is to extract the information from the noisy signal which, in this case, may be difficult because neither the nature of the information nor the noise is known.

There is, however, another approach that draws from communications theory. In some communications systems, the information from many sources is combined into one signal which, from a statistical viewpoint, is nothing but noise. To extract specific information the receiver assumes that the information is present and determines if that assumption is consistent with the received signal[3].

The same approach may be used in a Sediment Trend Analysis as follows: (i) assume the direction of sediment transport over an area containing many sample sites; (ii) from this assumption, predict the sediment trend that should appear along a particular sequence of samples; (iii) compare the prediction with the actual trend that is derived from the selected samples; and (iv) modify the assumed transport direction and repeat the comparison until the best fit is achieved.

The important feature of this approach is the use of many sample sites to detect a transport direction. This effectively reduces the level of noise. The principal difficulty is that the number of possible pathways in a given area may be too large to mechanize the technique, or to try them all. As a result, the choosing of trial transport directions has, as yet, not been analytically codified (research is on-going to do this). At present, the selection of trial directions is undertaken initially at random; although the term "random" is used loosely in that it is not strictly possible to remove the element of human decision-making entirely. For example, a first look at the possible transport pathways may encompass all north-south, or all east-west directions. As familiarity with the data increases, exploration for trends becomes less and less random. The number of trial trends becomes reduced to a manageable level through both experience and the use of additional information (usually the bathymetry and morphology of the area under study). Following from the communications analogy, when a final and coherent pattern of transport pathways is obtained that encompasses all, or nearly all of the samples, the assumption that there is information (the transport pathways) contained in the signal (the grain-size distributions) has been verified, despite the inability to define accurately all the uncertainties that may be present.

4 THE USE OF R^2

In order to assess the validity of any transport line, we use the *Z*-score and an additional statistic, the linear correlation coefficient R^2, defined as:

$$R^2 = \frac{\sum_i (\hat{y}_i - \bar{y})^2}{\sum_i (y_i - \bar{y})^2}; \text{ where } \hat{y} = f(x_1, x_2, ...); \text{ and } \bar{y} = \frac{1}{N}\sum_i y_i$$

The value of R^2 can range from 0 to 1. The definition of R^2 is based on the use of a model to relate a dependent parameter y to one or more independent parameters $(x_1, x_2, ...)$. In our case, the model used is a linear one, which can be written as:

$$\hat{y} = a_o + a_1 \cdot x_1 + a_2 \cdot x_2$$

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[3]This is a process referred to as Code Division Multiplexing.

The data (y,x_1,x_2) are grain-size distribution statistics, and the parameters (a_0, a_1, a_2) are estimated from the data using a least-squares criterion. The dependent parameter is defined as the skewness and the independent parameters are the mean size and the sorting. We make an implicit assumption that grain size samples making up a transport line, if plotted in skewness/sorting/mean space (as in Figure AI- 4), would tend to be clustered along a straight line. The slopes of the straight line, which are the fitted parameters, would depend on the type of transport (fining or coarsening). While there is no theoretical reason to expect a linear relationship among the three descriptors, there is also no theory predicting any other kind of relationship, so using the principle of Occam's Razor[4], we choose the simplest available relationship as our model. High values of R^2 (0.8 or greater) together with a significantly high value of the Z-score give us confidence in the validity of the transport line.

A low R^2 may occur, even when a trend is statistically acceptable for the following reasons: (i) sediments on an assumed transport path are, in reality, from different facies and valid trend statistics occurred accidentally; (ii) the sediments are from a single facies, but the chosen sequence is only a poor approximation of the actual transport path; and (iii) extraneous sediments have been introduced into the natural transport regime, as in the case of dredged material disposal. R^2, therefore, is assessed qualitatively and, when low, statistically acceptable trends must be treated with caution.

5 INTERPRETATION OF THE X-DISTRIBUTION

The shape of the X-distribution is important in defining the type of transport occurring along a line (erosion, accretion, total deposition, *etc.*), and thus the computation of X is important. Let us suppose that we have defined a transport line containing N source/deposit (d_1/d_2) pairs. Then we define X as:

$$X(s) = \sum_{i=1}^{N} \frac{(d_2)_i(s)}{(d_1)_i(s)}$$

Often d_2 in one pair is d_1 in another pair, and vice versa. Mean values of d_2 and d_1 are computed through:

$$\bar{d}_1(s) = \sum_{i=1}^{N} (d_1)_i(s); \text{and } \bar{d}_2(s) = \sum_{i=1}^{N} (d_2)_i(s)$$

Note that we do not define X as the quotient of the mean value of d_2 divided by the mean value of d_1, even though the results of the two computations are often almost identical. For ease of comparison, d_1, d_2, and X are normalized before plotting in reports, although there is no reason to expect that the integral of the X distribution should be unity.

$X(s)$ may be thought of as a function that describes the relative probability of each particle being removed from d_1 and deposited at d_2. It must be emphasized that the processes responsible for the transport of particles from d_1 to d_2 are unknown; they may in one

[4]Occam's Razor: Entities ought not to be multiplied except from necessity. (Occam, 14th Century philosopher, died 1349)

environment be breaking waves, in another tidal residual currents and, in still another, incorporate the effects of bioturbation.

Examination of *X*-distributions from a large number of different environments has shown that five basic shapes are most common when compared to the distributions of the deposits $d_1(s)$ and $d_2(s)$ (Fig. AI-6). These are as follows:

(1) Dynamic Equilibrium: The shape of the X-distributions closely resembles $d_1(s)$ and $d_2(s)$. The relative probability of grains being transported, therefore, is a similar distribution to the actual deposits. Thus, the probability of finding a particular sized grain in the deposit is equal to the probability of its transport and re-deposition (i.e., there must be a grain by grain replacement along the transport path). The bed is neither accreting nor eroding and is, therefore, in dynamic equilibrium.

An X-distribution signifying dynamic equilibrium may be found in either Case B or Case C transport suggesting that there is "fine balance" between erosion and accretion. Often when such environments are determined, both Case B and Case C trends may be significant along the selected sample sequence. This is referred to as a "Mixed Case", and when this occurs it is believed that the transport regime is also approaching a state of dynamic equilibrium.

(2) Net Accretion: The shapes of the three distributions are similar, but the mode of X is finer than the modes of $d_1(s)$ and $d_2(s)$. The mode of X may be thought of as the size that is the most easily transported. Because the modes of the deposits are coarser than X, these sizes are more readily deposited than transported. The bed, therefore, must be in a state of net accretion. Net accretion can only be seen in Case B transport.

(3) Net Erosion: Again the shapes of the three distributions are similar, but the mode of X is coarser than the $d_1(s)$ and $d_2(s)$ modes. This is the reverse of net accretion where the size most easily transported is coarser than the deposits. As result the deposits are undergoing erosion along the transport path. Net erosion can only be seen in Case C transport.

(4) Total Deposition I: Regardless of the shapes of $d_1(s)$ and $d_2(s)$, the X-distribution more or less increases monotonically over the complete size range of the deposits. Sediment must fine in the direction of transport (Case B); however, the bed is no longer mobile. Rather, it is accreting under a "rain" of sediment that fines with distance from source. Once deposited, there is no further transport. The occurrence of total deposition is usually confined to cohesive, muddy sediments.

(5) Total Deposition II (Horizontal X-Distributions): Occurring only in extremely fine sediments when the mean grain-size is very fine silt or clay, the X-distribution may be essentially horizontal. Such sediments are usually found far from their source and the horizontal nature of the X-distribution suggests that their deposition is no longer related strictly to size-sorting. In other words, there is now an equal probability of all sizes being deposited. This form of the X-distribution was first observed in the muddy deposits of a

British Columbia fjord and is described in McLaren, Cretney et al., 1993. Because the trends occur in very fine sediments where any changes in the distributions are extremely small, horizontal X-distributions may be found in both Case B and Case C trends.

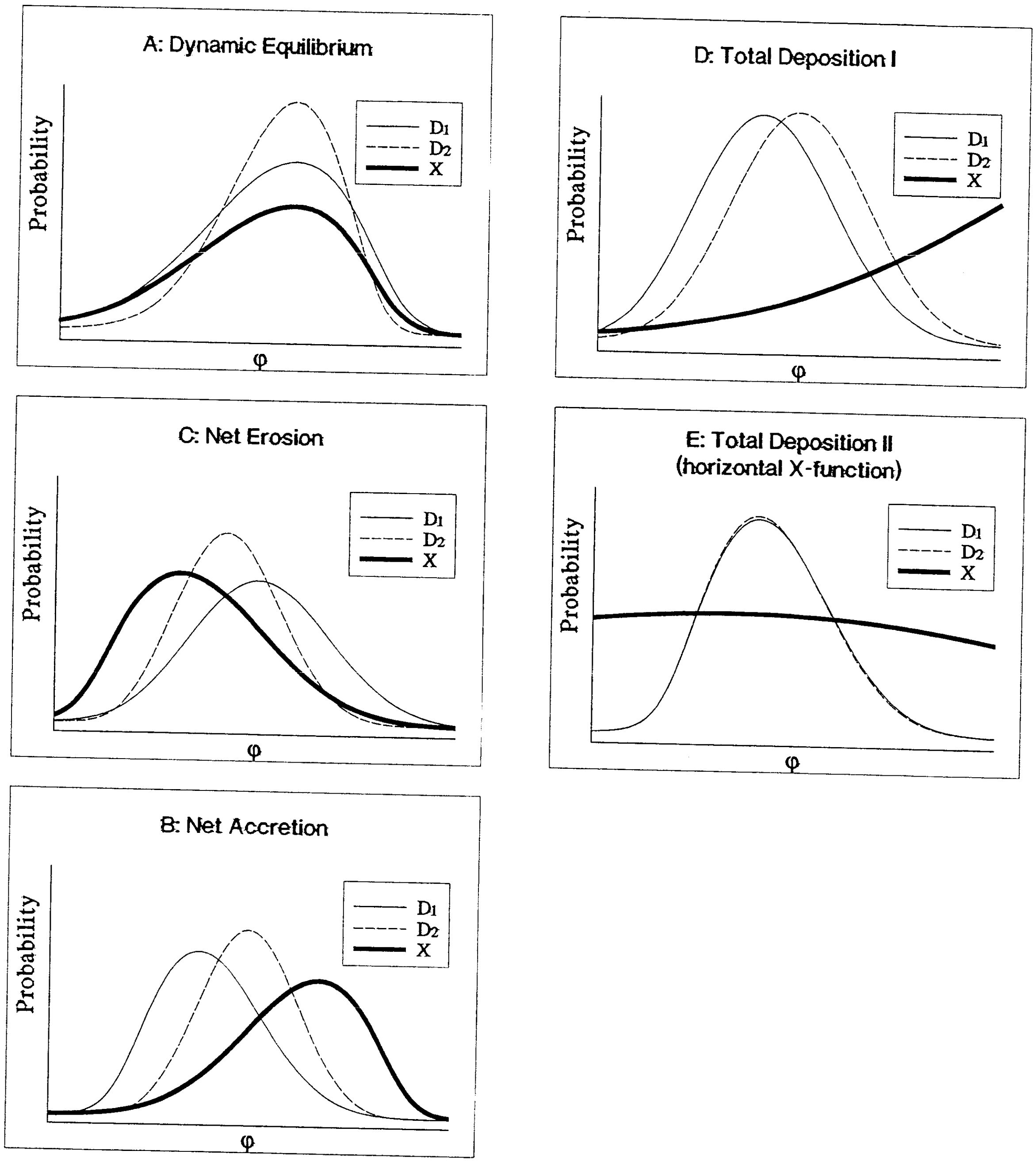

Figure AI- 6: Summary of the interpretations given to the shapes of X-distributions relative to the D1 and D2 deposits.

6 REFERENCES

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