RASER RIVER
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SEDIMENT TRANSPORT AND ITS ENVIRONMENTAL IMPLICATIONS IN THE LOWER FRASER RIVER AND FRASER DELTA

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SEDIMENT TRANSPORT AND ITS ENVIRONMENTAL IMPLICATIONS IN THE LOWER FRASER RIVER AND FRASER DELTA

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DISCLAIMER

Funding for this project was provided by Environment Canada through the Fraser River Action Plan, Canadian Coast Guard, Geological Survey of Canada and Greater Vancouver Regional District. The objective was to determine sedimentation patterns within the present-day fluvial and marine environments of the Fraser River Delta. It is recognized that further detailed study should be conducted in specific river reaches and intertidal areas to better understand local sedimentation patterns relative to different current and tidal conditions.

The views expressed herein are those of the authors and do not necessarily state or reflect those of the funding agencies.

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NOTE TO THE USER

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ABSTRACT

A sediment trend analysis was undertaken on about 1500 grab samples collected from the lower Fraser River, the delta and its foreslope. This is a qualitative technique whereby relative changes in the grain-size distributions of the bottom sediments are used to establish net patterns of sediment transport. In addition, the method provides information on the behaviour of the bed material with respect to accretion, net erosion or dynamic equilibrium.

Samples were collected on a regular grid spacing varying from 100 m to 1 km between Feb. 9 and April 7, 1993. They were obtained principally with a Shipek sampler enabling the top 10 to 15 cm of sediment to be collected. The complete grain-size distribution of each sample was obtained by sieving at 0.5 phi intervals material between 4 mm (-2ϕ) and 1 mm (0ϕ). A Malvern laser size analyzer was used for the range between 1.8 mm to 1.0μ (-0.85ϕto 10.0ϕ): where both size fractions were present, the sieve and laser data were merged to form one complete distribution. Because sampling took place prior to the freshet, the derived transport pathways, particularly in the river, may be a reflection of pre-freshet conditions rather than general conditions throughout the year.

Separate transport trends are established for two sediment types; sand (including muddy sand) and mud (including sandy mud). The former comprises the majority of the data base (65 % of the samples) and is found mainly in the river and on the tidal flats. Sand trends in the river, while generally showing a net movement of material from the upstream end of the study area to all the exits into the Strait of Georgia, also reveal the existence of upstream transport (reversals) in a number of channels. In many cases, the presence of a reversal correlates with regions of known channel instability and/or high rates of deposition (e.g., in the vicinity of Mitchell Island on the North Arm, Steveston Cut and the trifurcation area at New Westminster).

Trends in the upper river from Douglas Island to west of Annacis Island, and in the North Arm, generally show net accretion (although the Pitt River reversal suggests net erosion). The statistics for the trends in the North Arm are very weak, for reasons that are not clear. No sand was traced from the North Arm beyond the Point Grey Breakwater. Eroding transport conditions are found in Middle Arm; however sand does not appear to be transported west of Swishwash Island onto Sturgeon Bank. In the South Arm west of Annacis Island, the natures of the trends become increasingly varied with many showing significant statistics for both accretion and erosion (a mixed case), or erosion only.

In Steveston Cut and Steveston Bend, transport trends can be extended as far as Sand Heads along the north bank only. The central and south portions of the channel are characterized by a counterclockwise gyre suggesting the presence of a sediment return system from Sand Heads to as far upriver as Blair Point east of Steveston. The nature of the trends are generally varied with erosion dominating the outflow on the north side, and either a mixed case or deposition occurring on the south side. Despite the variability between

erosion and accretion, the trend statistics for this part of the river are exceptionally good.

Sand can be traced from the outflowing portion of the South Arm north and northeast onto Sturgeon Bank as far as the Iona outfall (north of the outfall the trends require "re-starting" and show net erosion over the intertidal flat in a clockwise gyre). There is also evidence for sand from the South Arm becoming incorporated in a clockwise gyre across the north half of Roberts Bank. The transport trends on either side of Steveston Channel show similarities, with net accretion taking place close to the river source and a mixed case and erosion occurring with increasing distance. No sand transport can be determined from the South Arm onto the delta foreslope below 50 m (in fact, no sandy sediments were obtained in the sampling program).

Good transport trends showing both erosion and accretion are present through Canoe Passage and onto the south half of Roberts Bank. These trends form a dendritic pattern across the intertidal flat suggestive of "normal" deltaic processes operating in this region.

The remaining tidal flats south of Westshore and Tsawwassen Terminals show clockwise circulation of sediment with sand originating from the delta foreslope below 50 m. Again, the trends are variable with both erosion and deposition in evidence. Sand transport in this region of the study area also follows the bathymetry of the delta foreslope between 50 m and 120 m in a northwest direction. These trends indicate net erosion, the source of sand evidently being derived from the erosion of the delta foreslope itself rather than receiving any present input from the Fraser River.

In comparison to sand, mud deposits play a minor role in the river. They are generally found on the sides or banks of the main channels and their trends most often are associated with reversals into backwaters where total deposition (i.e., once deposited, there is no further transport) is observed. Mud is also relatively rare on the intertidal flats being confined principally to the landward margins. Where transport trends could be determined, the derived patterns follow closely those for sand. Mud is confined mainly to the delta foreshore below 50 m where excellent accretionary trends follow the bathymetry in a northward direction.

Using the results of the sediment trend analysis it is suggested sand deposition over most of the intertidal flats is no longer the result of "normal" deltaic processes. In particular, sand passing down the South Arm, on reaching Sand Heads, must be transported back onto the tidal flats through littoral, rather than deltaic processes. Only through Canoe Passage do the trends follow the expected transport paths indicative of a delta formation. Here, as well as elsewhere on the Banks, many of the trends show either a mixed case (erosion and accretion) or net erosion only, a finding that occurs when sediment supply is small. The evident paucity of sand on the tidal flats is attributed principally to channelization and removal of river sands by dredging, although the various causeways and jetties crossing the Banks may also be a contributing factor. It is recommended that sediment removal from the river should be, as far as possible, avoided if the tidal flat environment as it now exists is to be protected from either erosion or a change in sediment type.

The evidence for a sediment return system into Steveston Bend and Steveston Cut may, in part, be caused by dredging activities in the river throughout the study area which has lowered bed levels in recent years. In many estuaries, it has been found that over-deepening increases the tidal range resulting in stronger flood currents. It is suggested that future engineering works in Steveston Bend designed to decrease dredging requirements might take a landward return of sediments into account. It is not known if the same transport patterns take place during freshet.

The findings also suggest that Canoe Passage is a favoured location for the main outflow of the Fraser River. The route is shorter and erosion on the adjacent foreslope may be adding a contributing pressure for the river to change its course. The erosion on the foreslope may be endangering the stability of the Coalport and Tsawwassen Terminals and is probably the result of the channelization of the South Arm which effectively removes sediment replenishment to this area. Although, present plans are to avoid allowing the river to flow through Canoe Passage, it is suggested that there are several aspects that might be worth considering in favour of such a course change. Apart from a probable decrease in dredging efforts, and allowing deposition in an area known to be eroding, there are, today, major changes in the philosophy of engineering that seek to "work with nature", rather than continually to upgrade control measures which, in the long term, often result in failure.

Three new dredge material disposal sites are proposed in order to decrease erosion of the foreslope of southern Roberts Bank, and to maintain sedimentation on northern Roberts Bank and Sturgeon Bank.

Finally the transport pathways provide a basis to assess the probable behaviour of contaminants associated with the sediments. Six sites are proposed in environments of total deposition where longterm contaminant monitoring programs may provide the most useful results. A seventh site is selected along the length of the delta foreslope in an environment of net accretion. The establishment of a monitoring program at this locality will reflect changing conditions for the whole of the Fraser River.

1.0 INTRODUCTION

1.1 Background

Since the turn of the century, the lower Fraser River has undergone significant physical modifications such as diking for flood control, dredging to maintain navigable channels and to supply aggregates, channel stabilization works and jetty construction at the mouths of the principal distributaries. Water quality is affected by discharges which include effluents from agricultural, industrial and urban land, municipal outfalls, landfill leachates, and both accidental and illegal spills.

As a result of both the above factors, Environment Canada and the Canadian Coast Guard have identified a requirement to establish the net patterns of sediment transport, as well as the dynamic behaviour of the sediments. Environment Canada, as part of the Fraser River Action Plan (FRAP), in cooperation with other federal and provincial partners, is presently implementing an assessment program to determine current levels of contamination and to measure changes in environmental quality, especially in relation to pollution abatement measures. Because many contaminants are known to associate with fine sediments, and their behaviour is linked to the processes of sediment transport, a rational monitoring program can be greatly helped by an understanding of the sediment transport regime. The same information is required by the Canadian Coast Guard in order to design more effective dredging programs and to select the best disposal sites for dredged material.

Unfortunately, sediment transport is generally difficult to model, particularly in the case of estuaries, for a variety of reasons. Water movements are tidally dependent, changing in their direction, intensity and duration; also small errors in grain-size characteristics, bathymetry, bed type and bed friction can create significant errors in the solution (Black and Barnett, 1988). Often, natural erosion or deposition rates are too slow for bed changes to be measured for comparison with model predictions. Thus, any method that can help to calibrate the results of a transport model would greatly enhance its reliability as a predictive technique.

The principal aim of this report, therefore, is to establish the net transport patterns using a relatively new technique known as a Sediment Trend Analysis. First described in McLaren and Bowles, 1985, this approach uses for its data, relative changes in complete grain-size distributions of the existing sediments. The derived patterns of transport are, in effect, an integration of all processes responsible for the erosion, transport and deposition of sediments over the time period required to form the deposits. In addition, the analysis provides information on the probability of each grain-size being transported which directly relates to the dynamic behavior of the sedimentological environment.

Although this approach is largely qualitative (it is unable to establish rates of transport or deposition), the results have been particularly useful in a large variety of studies to: (1) evaluate and direct numerical models (Van Heuvel, et

al., 1993; McLaren, Collins et al., 1993); (2) determine the behavior of sediments at dredged material disposal sites (McLaren and Powys, 1989); (3) predict the build-up and dispersal of contaminated sediments (McLaren, Cretney et al., 1993; Little and McLaren, 1989); and (4) understand the sediment and process interrelationships among natural marine and coastal environments (De Meyer and Wartel, 1988).

1.2 Objectives

The following lists the specific objectives originally specified for this project. The degree to which these objectives have been met, together with the location in the report where each is discussed, are included in parenthesis.

(1) Analyze 1,488 sediment grab samples [1] for their complete grain-size distribution. (This objective was completely fulfilled; see Section 1.4 and Appendix IV.)

(2) Determine patterns of net sediment transport in the lower Fraser River and the Fraser foreshore and offshore to a depth of 200 m into the Strait of Georgia using the technique of "Sediment Trend Analysis". (This objective was completely fulfilled; see Section 4.0 and Figures 4 and 6.)

(3) Determine areas of erosion, stability (dynamic equilibrium) and deposition for both fine and coarse sediments. (This objective was completely fulfilled; see Figures 4 and 6.)

(4) Determine the probable dispersal and/or accumulation of contaminants contained in the bottom sediments. (See Section 5.3.)

(5) Correlate the derived patterns of transport with known processes and related water movement studies. (This objective is discussed in appropriate places throughout the Discussion; see Section 5.0.)

(6) Use the above findings in order to:

(i) Identify areas of deposition of fine sediments (clays and silts) and coarse sediments (sands). (See Figures 4 and 6.)
(ii) Relate sedimentation patterns to navigation channel locations with a view to modifying channel location where feasible or optimizing dredging program management. (See Sections 5.2 and 5.2.1.)
(iii) Recommend in water disposal sites for dredge material in order to minimize possible engineering and environmental consequences. (See Section 5.2.1 and Figure 7.0).
(iv) Assess the future behaviour (i.e., further transport burial, etc.) of sediments known to be contaminated or the potential impacts of migration of contaminated sediments to areas which are not contaminated but actively dredged. (The principles of this objective are discussed in Section 5.3; however, specific data on contaminated sediments are, at present, insufficient to meet fully this objective.)
(v) Suggest, if applicable, possible solutions to mitigate the environmental

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[1] These samples were collected during a previous phase of this study. The sampling strategy and collection are described in 1.3 Field Methods.

consequence of contaminants accumulating in the bottom sediments. (This objective is partially met in Section 5.3 through the recommendation of monitoring sites.)
(vi) Discuss, in consultation with the clients, other related harbour management concerns. These may include the effects of harbour development, the location of outfalls, shoreline erosion, and oil spill contingency planning. (No further concerns were expressed by the clients during the preparation of this report.)

1.3 Field Methods

Field work was carried out in an earlier phase of this study between February 9 and April 7, 1993. The vessels WASUCA (Environment Canada) and SEXTON (Public Works Canada) were used for all of the river sampling and some of the sample collection in the Strait of Georgia. An American charter vessel, BRENDAN "D" II, completed the offshore sampling in the Strait of Georgia. Positioning was achieved by a non-differential GPS [2] (Global Positioning System) and the samples were collected with a Shipek Grab, a device that enabled about the top 10 to 15 cm of surface sediment to be sampled. In general, the Shipek worked extremely well. A small representative sub-sample (about 100 gm) from the grab was stored in sealed plastic bags and shipped to the GeoSea (UK) office in Cambridge for size analysis. The Canadian Coast Guard, Search and Rescue hovercraft was used to sample the intertidal flats (Roberts and Sturgeon Bank) and these samples were collected with a trowel.

To ensure an adequate number of samples for establishing the sediment transport regime, sampling for the river portion of the study was carried out on a series of transects spaced 500 m apart. On each transect, samples were equally spaced at about 100 m apart. Where the river was narrow, a sample was collected in the centre of the main channel and mid-way from the centre to the bank on either side. On the intertidal banks, samples were collected on a regular grid of 500 m spacing, and in the offshore the interval was increased to 1 km (Fig. 1). The westward extent of the offshore sampling was limited by the 200 m bathymetric contour. In all, a total of 1,488 samples were collected.

It must be noted that sampling was carried out prior to the onset of the freshet when it might be expected that the relative importance of tidal processes over river processes is greater than actually during the freshet. Thus the sediment trend analysis may be reflecting a seasonal transport pattern which could be different in the post-freshet period.

1.4 Grain Size Analyses

All samples were analyzed on a Malvern 2600L laser particle-size analyzer following a standarized technique developed by GeoSea. This instrument

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[2] The accuracy of the GPS is subject to change in accordance with American DOD civil users policy. It is also dependent on the positions of the satellites that the unit is using. The worst case accuracy could be as much as 60 m but is more typically less than 15 m. For the purposes of a Sediment Trend Analysis even the worst case accuracy would have no effect on achieving results.

measures the diffraction pattern caused by sediment particles as they are pumped in a water suspension through a laser beam. The instrument uses lenses of different focal lengths to measure the concentration of particles encompassing a maximum size range of 1800 microns (μ) to 1.0 μ (-0.85 ϕ to 10.0 ϕ). An analysis typically requires the use of two lenses; the 100 mm lens (range 2.5 ϕ to 10.0 ϕ; 177 μ to 0.98 μ) and the 600 mm lens (range -0.5 to 6.5 ϕ; 1.41 mm to 11.05 mm). Material larger than 1.0 mm (0.0 ϕ) is dry sieved at 0.5 ϕ intervals.

Prior to analysis, the alignment of the laser beam and the receptor diode are checked. Sample details are recorded and a background measurement is taken of the clean water in the dispersion tank. This "noise" is subtracted from the sample measurements by the Malvern software.

The sample is first well mixed by hand to ensure obtaining a representative sub-sample. The amount of sample required depends on the sediment type which in turn determines the degree of obscuration (the amount of light blocked by the particles). The optimum obscuration is about 20 per cent which is obtained with approximately 4 to 5 g of sand or as little as 1 g of silt and clay. The sub-sample is introduced into the water bath of the Malvern by wet sieving through a 1 mm sieve. This eliminates possible blockage of the sample pump by too large particles. Should any material remain on the 1 mm sieve, then the weight percentages for the coarse material (-2.0 ϕ to 0.0 ϕ; 4.00 mm to 1.00 mm) are derived by dry sieving a portion of the original sample.

In the Malvern, disaggregation of the sample is achieved by both mechanical stirring and ultrasonic dispersion in the water bath. The instrument measures two distributions that are then averaged. Samples are ordinarily measured first on the "sand" lens (600 mm). If it is seen that more than 5 per cent is finer than 10 μ the sample is run a second time on the 100 mm lens to determine the distribution of the fine silt and clay. GeoSea has developed software that allows the gravel and the measurements on specific lenses to be merged into a final distribution within the range of -2.0 ϕ (4 mm) and 10.5 ϕ (1 μ).

The data are provided as hard copy (Appendix IV) together with an ASCII file (*.DAT). The latter is formatted so that the data for each sample are contained in a single line. The first line in the file defines the variables and the phi scale, and is followed by the weight percentages for the samples. The moment measures of mean, sorting (variance), and skewness are also provided. A small plotting program (GRAIN.EXE) allows the distributions to be viewed easily and printed. The database can also be provided in Microsoft Excel format (*.EXL)

A copy of the data base, including a disk file, was previously submitted to the client (GeoSea Consulting (Canada) Ltd., 1994). A further EXCEL file has been provided where the geographical coordinates of each sample are included together with the grain sizes in millimetres and microns, and percent silt, clay and sand (FRASER.EXL).

2.0 THEORY

The technique to determine the sediment transport regime utilizes the relative changes in grain-size distributions of the bottom sediments. The derived patterns of transport are, in effect, an integration of all processes responsible for the transport and deposition of the bottom sediments. The latter may be considered as a facies that is defined by it's grain-size distribution. Details of the theory are described in Appendix I; however, the approach is summarized here.

Suppose two sediment samples (D_1 and D_2)[3] are taken sequentially in a known transport direction (for example from a river bed where D1 is the up-current sample and D_2 is the down-current sample). The theory shows that the sediment distribution of D_2 may become finer (Case B) or coarser (Case C) than D_1; if it becomes finer, the skewness of the distribution must become more negative. Conversely, if D_2 is coarser than D1, the skewness must become more positive. The sorting will become better (i.e., the value for variance will become less) for both Case B and C. If either of these two trends is observed, we can infer that sediment transport is occurring from D_1 to D_2. If the trend is different from the two acceptable trends (e.g. if D_2 is finer, better sorted and more positively skewed than D_1), the trend is unacceptable and we cannot suppose that transport between the two samples has taken place.

In the above example, where we are already sure of the transport direction, $D_2(s)$ can be related to $D_1(s)$ by a function X(s) where 's' is the grain size. The distribution of X(s) may be determined by:

$$X(s)= D_2(s)/D_1(s)$$

X(s) provides the statistical relationship between the two deposits and its distribution defines the relative probability of each particular grain size being eroded, transported and deposited from D_1 to D_2.

2.1 Interpretation of the X-Distribution

Empirical examination of X-distributions from a large number of different environments has shown that four basic shapes are most common when compared to the D_1 and D_2 distributions (Fig.A-5; Appendix I). These are as follows:

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[3] A sample is considered to provide a representation of a sediment type (or facies). There is no direct time connotation, nor does the depth to which the sample was taken contain any significance (provided, of course, 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. It is unable to determine the rate of deposition at either locality, but frequently the derived patterns of transport do provide an indication of the probable processes that are responsible in producing the observed sediment types.

(1) Dynamic Equilibrium: The shape of the X-distribution closely resembles the D_1 and D_2 distributions. The relative probability of grains being transported, therefore, is a similar distribution to the actual deposits. This suggests that the probability of finding a particular grain in the deposit is equal to the probability of its transport and re deposition (i.e., there is a grain by grain replacement along the transport path). The bed is neither accreting nor eroding and is, therefore, in 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 and D_2. Sediment must fine in the direction of transport; however, more fine grains are deposited along the transport path than are eroded, with the result that the bed, though mobile, is accreting.

(3) Net Erosion: Again the shapes of the three distributions are similar, but the mode of X is coarser than the D_1 and D_2 modes. Sediment coarsens along the transport path, more grains are eroded than deposited, and the bed is undergoing net erosion.

(4) Total Deposition: Regardless of the shapes of D_1 and D_2, the X-distribution more or less increases monotonically over the complete size range of the deposits. Sediment must fine in the direction of transport; 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.

Recently, a fifth form of the X-distribution (not described in Appendix I) has been discovered. 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.

2.2 Interpretation of a Trend

In reality, a perfect sequence of progressive changes in grain-size distributions is seldom observed in a line of samples, even when the transport direction is clearly known. This is due to complicating factors such as variation in the grain-size distributions of source material, local and temporal variability in the X(s) function, and a variety of sediment sampling difficulties (i.e., sample doesn't adequately describe the deposit; it's taken too deeply; not deep enough etc.).

Initially, a trend is easily determined using a statistical approach whereby, instead of searching for "perfect" changes in a sample sequence, all possible pairs contained in the sequence are assessed for possible transport direction. When one of the trends exceeds random probability within the sample sequence, we infer the direction of transport and calculate X(s). The precise statistical technique is described more fully in Appendix I.

Despite the initial use of a statistical test, various other qualitative assessments must be made in the final acceptance or rejection of a trend.

Included is an evaluation of R^2, a multiple correlation coefficient defining the relationship among the mean, sorting and skewness in the sample sequence. If a given sample sequence follows a transport path perfectly, R^2 will approach 1.0 (i.e., the sediments are perfectly "transport-related"). A low R^2 may occur, even when a trend is statistically acceptable for the following reasons: (i) sediments on a presumed 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 accepted trends must be treated with caution.

To analyze for sediment transport directions over 2-dimensions, a grid of samples is required. Each sample is analyzed for its complete grain-size distribution and these are entered into a micro-computer equipped with appropriate software to "explore" for statistically acceptable trends. The technique to explore for transport pathways is initially undertaken randomly [4] (i.e., up and down the river, across the river, lines of samples running east-west, north-south etc.). As familiarity with the data increases, exploration becomes less and less random until a single and final coherent pattern of transport is obtained [5]. On completion of an interpretation, each transport line may then be used to derive a corresponding X(s) function from which the behaviour of the bed material on the transport path is inferred.

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[4] The term "random" is used loosely in that it is not strictly possible to remove the element of human decision-making entirely. The important aspect of the initial search for sediment trends is that it is undertaken with no preconceived concept of transport directions. It is, however, assumed that there will be a net sediment transport pattern and that changes in the grain-size distributions throughout the study area will not be random. The derivation of the final patterns may be likened to communication theory which, in the case of extremely noisy signals, requires the "discovery" of a "message" as the proof that the message does indeed exist.

[5] At present, the approach of obtaining the final derivation of the net sediment transport pathways relies on assessing and removing "noise" qualitatively. The GeoSea trend programming is specifically designed to do this in that all sample distributions may be readily compared with one and other (and excessively noisy distributions discarded), the best sediment types can be determined for the analysis, and the relationships among all the sample pairs may be assessed. Because we are unable to know the exact nature of the "noise" that we may be confronted with, it is difficult at this stage to devise a quantitative technique to eliminate it. To do so is the subject of much on-going research, not only by GeoSea, but at the Universities of Southampton (U.K.), Ghent (Belgium), Aarhus (Denmark), Utrecht (Holland) and South Africa.

3.0 PHYSICAL SETTING

3.1 Geology and Physiography

The Fraser Delta began its growth immediately following deglaciation about 11,000 to 13,000 years ago (Clague et al., 1983). According to Neu (1966), initial deposition began in the region where Pitt Valley joins the Fraser Valley; however, the present delta is considered to begin where the North and South Arms bifurcate near New Westminster. Delta deposits overlie late Pleistocene till and are over 200 m thick (Johnston, 1921). The lowest stratigraphic unit is comprised of prodelta mud that is followed by a thick succession of foreset beds. South of the main distributary channel (South Arm), the latter tend to be sandy. To the north, the foreset beds contain more silt interspersed with thick localized sand bodies. The topset beds are typically sand derived from distributary channels and these can be overlain by mud and peat that are primarily of floodplain and bog origin (Luternauer et al., 1993).

The present delta surface is heavily urbanized and a dike separates the delta top from extensive tidal flats that make up Roberts and Sturgeon Banks. A discontinuous fringe of marsh underlain by muddy sediments marks upper high water. The intertidal flats gently slope seawards for about 9 km and are frequently characterized by sand swells with heights of 0.5 m and wavelengths of 50 to 100 m (Mathews and Shepard, 1962; Luternauer, 1980). They are considered to have international ecological importance, particularly as bird habitat (Vermeer and Butler, 1987). Beyond the tidal flats, the delta foreslope [6] extends 5 to 10 km into the Strait of Georgia to a depth of 300 m. A number of papers have described the existence of sea valleys that cut the foreslope, the result of turbidity currents and debris flows (see Luternauer et al., 1993, for a full set of references). These have up to 10 m of relief and extend from the edge of the tidal flats to water depths of more than 200 m. The largest, and currently active, of these occurs off Sand Heads (Evoy et al., 1993).

The samples collected for this study provide one of the most complete determinations of sediment types present for the lower Fraser River and its delta (Fig.2). In general, the river and intertidal flats are dominated by sand. Mud is found on the river sides, in backwaters and on the foreslope in depths below 50 m. Muddy sediments are more common in the North Arm compared to the South Arm, and the presence of mud and sandy mud clearly delineates the fringe marshes along the high water line of the intertidal flats.

The mean river discharge from the Fraser River into the Strait of Georgia is about 3,400 m^3s^{-1} (McLean and Church, 1986) and typically exceeds 10,000 m^3s^{-1} from June to mid-July [7]. In winter, flows are much less and by mid-March discharge has typically diminished to about 1,000 m^3s^{-1} (Thomson, 1981). Of the total discharge in Queen's Reach, 6% is contributed by the Pitt River. The North Arm discharges 16% of the total (Acres, 1984), 70% flows out

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[6] In this report, the delta foreslope is taken to mean the submarine portion of the delta from low low water level to its toe at about the 300 m isobath.

[7] Based on data at Mission.

past Steveston (Hay, 1988) and the remaining 14% of the flow is discharged through Canoe Passage. The amount of sediment generated by this discharge is about 17×10^6 t, of which 35% is sand (McLean and Tassone, 1991). The distribution of sediment flow has not been investigated in any detail, but it is known that the proportion of sand to mud in transport is greatest in the South Arm (Kostachuk and Luternauer, 1987); and it is believed that only 3% to 9% of the entire sediment load enters the North Arm (Church et al., 1990).

3.2 Tides and Currents

Tidal range at Sand Heads is relatively high, ranging from 2.6 m to over 5.4 m (Luternauer and Finn, 1983). Flood tidal currents are northwest and tend to be stronger and of longer duration than the southeast flowing ebb. Over the delta slope, the tidal currents parallel the bathymetry and are strong enough to transport sand-sized material (Pickard, 1956; Luternauer et al., 1978). Within the Fraser River estuary, the semi-diurnal tides are superimposed on the fluvial regime. The effects of the tide can be felt as far as 98 km upriver. More than 40% of the tidal flow branches off the main stream and propagates through Pitt River into Pitt Lake where it causes a fluctuation of the lake level of more than 1 m during low discharge conditions (Ashley, 1977).

The saltwedge associated with the incoming tide is dependent on the flow conditions of the river and may reach as far as Annacis Island. For flows exceeding 5000 m^3s^{-1} it rarely extends more than 10 km (Steveston Bend) (Ages and Woolard, 1976). The direction of currents may reverse abruptly with depth at the seaward end of the estuary when the salt wedge is in the river. It is not uncommon in the lower reaches of the South Arm for a 1 m s^{-1} down-river surface current to overlie a 1 m s^{-1} up-river current at a depth of about 6 m (Thomson, 1981).

3.3 Anthropogenic Disturbances

The earliest modifications to the river began with diking that has served to channelize the river and its floodplain in order to protect against flooding and extreme tides. The principal effect of diking is to eliminate sediment loss from the river to its natural flood plain, thereby increasing the amount of deposition both in the river and at its mouth. Paradoxically, these effects conflict with dredging and maintaining navigable shipping channels, endeavours that have been on-going since before the turn of the century in order to obtain deep water from the Strait of Georgia to New Westminster. Neu (1966) has written an excellent historical account of the river works that have been constructed to help maintain navigable channels and to mitigate dredging requirements. Of particular interest is the history of the Steveston Jetty that was constructed between 1908 and 1937 to establish a stable passage through Roberts and Sturgeon Banks. Other channel works include submerged dams, jetties, guiding structures, closure of minor arms and bank protection. More recent constructions on the Banks include the Tsawwassen ferry terminal, a coal port and its associated causeway, and a deep sea sewage outfall (also with a causeway) at Iona Island.

Today, it is a goal to maintain a channel 10 m deep from Sand Heads to New Westminster for 95% of the time. Up to 1989 this was achieved 30% of the

time (Stewart and Tassone, 1989) [8]. According to Public Works Canada (1989), over the period 1974 to 1984 dredging averaged about $7x10^6$ m^3 y^{-1} with borrow dredging (i.e., mining) reaching up to $3x10^6$ m^3 y^{-1} and the remainder dumped either in upland sand stockpiles or in the offshore west of Sand Heads. McLean and Tassone (1991) have demonstrated that the quantity dredged is about twice the incoming bed material load and as a result the river bed has lowered in most places 8 cm y^{-1} from 1974 to 1984. An exception is at Sand Heads and Steveston Cut where, in recent years, dredging efforts have nearly doubled with little change in bed level (Public Works Canada, 1989) [9]. An excellent overview of dredging activities is provided in Ferguson, (1991).

In addition to the physical modifications brought about by river control structures and dredging, there are also known environmental impacts from the discharge of pollutants (Stancil, 1980; Swain, 1980). These accumulate in the water, sediment and biota and include fecal coliforms, PCB's, chlorinated phenolics, some metals and dioxins and furans (Norecol Environmental Consultants Ltd., 1993). Habitat modification is reported in the vicinity of the former Iona surface outfall and in many of the Fraser River backwaters (Standing Committee on the Fraser River Estuary Water Quality Plan, 1990).

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[8] Updated information from Public Works indicates that the goal was to maintain the channel at 10.7 m and that this was accomplished 30% of the time for a two lane navigation channel; the one lane condition being achieved much more frequently.

[9] This finding in the Public Works Canada (1989) report may be of considerable significance with respect to understanding the sediment dynamics in this part of the river. However, Public Works (in reviewing a draft of this report) now believe that the statement may not be correct. There are, at present, engineering and modeling studies that may provide a more exact understanding of the relationships between dredging and bed lowering that have occurred in the recent past.

4.0 PATTERNS OF SEDIMENT TRANSPORT (RESULTS)

Size analyses of the 1,488 samples collected from the lower Fraser River and the Strait of Georgia (not including duplicates), revealed the percentage of samples characterized by each of the following sediment types [10] (types 4 to 7 are mapped on Figure 2):

(1) gravel (-2ϕ to -1ϕ; 4 mm to 2 mm) - 0%

(2) sandy gravel - 1%

(3) gravelly sand - 1%

(4) sand (-1ϕ to 4ϕ; 2 mm to 62.5 μ) - 54 %

(5) muddy sand - 11%

(6) sandy mud - 18%

(7) mud [11] (4ϕ to 10ϕ; 62.5 μ to 1 μ) - 15%

Because previous studies have shown that different sediment types may behave differently from each other, considerable effort was made to establish separate transport patterns for each type. In particular, mud which is usually a cohesive sediment, may follow different transport paths from non-cohesive sand, and bimodal distributions often behave according to the proportion of mud present in the distribution. In this study, however, sandy sediments are by far the most dominant and a final interpretation was established for sand and muddy sand as one sediment type. A second interpretation was obtained using mud and sandy mud. These will be referred to as the sand and mud facies respectively.

Following the calculation of numerous sample sequences to determine significant trends, a total of 175 lines were selected to provide a pattern of transport for sand (Figs.3A, 3B, and 3C). The individual trend statistics are contained in Appendix IIA. Figures 4A, 4B and 4C illustrate the net sediment transport pathways for sand. For ease of discussion, the large number of lines has been grouped into 19 "sediment transport environments" (Fig.3 and Table 1A). Again, for the sake of simplification, all the grain-size distributions and the resultant X-distributions are contained as Figures in Appendix III and are referenced in Table 1.

A similar format is used for the mud trends that are shown in 67 sample lines (Figs. 5A, 5B, and 5C). These trends agreed closely with the sand trends, thereby providing a high degree of mutual support for the interpretation of both sediment types. An attempt was made to maintain identical sediment

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[10] The sediment types use 20% and 50% as "cut-off" limits. For example, sand has less than 20% of any other size; sandy mud has greater than 20% sand, but less than 50%; muddy sand has greater than 20% mud, but less than 50%; etc.

[11] Mud contains both silt and clay sizes. The size boundary between silt and clay is usually placed at 8ϕ (3.9 μ) although 9ϕ (2 μ) is sometimes used. Because mud is generally a unimodal distribution, it would be incorrect to divide silt and clay into separate sediment types for a trend analysis.

transport environments for mud as for sand (Fig. 5 and Table 1B); however, in some of the sand environments there was no mud and vice versa. The net sediment transport paths for mud are illustrated in Figs. 6A, 6B, and 6C and Appendix III provides the example distributions for each of the environments described in Table 1B.

It is again emphasized that the derived patterns of transport are based on samples collected prior to freshet and may represent a pattern that is relevant only to that period.

Table 1A: Summary of sediment transport environments in the Fraser River/ Strait of Georgia for Sand. pp 17 - 20

Table 1B: Summary of sediment transport environments in the Fraser River/Strait of Georgia for Mud. pp 21 - 23

TABLE 1A: SUMMARY OF SEDIMENT TRANSPORT ENVIRONMENTS IN THE FRASER RIVER/STRAIT OF GEORGIA (SAND)

Transport Environment (See Figs.3A, 3B, and 3C)		**Lines**	**No. of Sample Lines**	**R2 Values**		**Notes**	**Figure Numbers**
				Mean	**S.D.**		**(Appendix III)**
1	Douglas Island (Fig.3A)	1 to 8	8	0.86	0.07	Accreting transport regime in the downstream direction; flow is concentrated on the left bank where there is slight erosion. All trends terminate in Queen's Reach.	AIII-1: AIII-2
2	Coquitlam River/ Pitt River (Fig.3A)	9 to 20	12	0.87	0.09	Coquitlam River appears to be an important source for transport up the Pitt River. Counterclockwise gyre around Tree Island. High energy transport indicating net erosion. Some evidence for transport into channel west of Douglas Island.	AIII-3
3	Queen's Reach/ Sapperton Channel (Fig.3A)	21 to 34	14	0.86	0.07	Accreting transport continues from the Douglas Island regime (1) into Sapperton Channel and forms a clockwise circulation around City Bank and into Queen's Reach. Upriver transport in Queen's Channel meets downriver transport of the Douglas Island regime in the vicinity of Sapperton Dike; high rates of deposition expected.	AIII-4

4	Eastern North Arm (Figs.3A and 3C)	35 to 40	6	0.49	0.31	Generally accreting in a downriver direction from New Westminster into the channel north of Mitchell Island. Slight erosion on left bank. Trends are poor.	AIII-5
5	South Mitchell Island (Fig.3C)	41 to 42	2	0.56	0.44	Counterclockwise gyre around Mitchell Island. Would expect high sedimentation in the south channel where transport meets the Eastern North Arm regime (4). Similar to the Eastern North Arm regime, the trends are poor.	AIII-6
6	Middle Arm (Fig.3C)	43 to 46	4	0.87	0.04	Generally eroding, downriver transport. Good trends, but become confused in the vicinity of Swishwash Island.	AIII-7
7	Western North Arm (Fig.3C)	47 to 51	5	0.28	0.37	Downriver accretion as far as the Point Grey breakwater. Beyond the breakwater, sand is rare and the grain-size distributions are confused. These trends are very poor.	AIII-8
8	City Reach/ Annacis Channel (Fig. 3A)	52 to 59	8	0.62	0.18	Mixed case transport suggesting a delicate balance between erosion and accretion in the vicinity of New Westminster. Net accretion throughout City Reach and Annacis Channel.	AIII-9
9	Gravesend Reach (Figs. 3A, 3B and 3C)	60 to 65	6	0.50	0.18	A mix of lines showing erosion and accretion with erosion somewhat favouring the right bank.	AIII-10
10	Woodward Reach (Figs. 3B and 3C)	66 to 71	5	0.85	0.14	Nearly all lines show net erosion in a downriver direction. Lines cannot be extended beyond Blair Point where they are abruptly terminated.	AIII-12

11	Ladner Reach/Canoe Passage/Sea Reach (Fig. 3B)	72 to 78	7	0.87	0.11	Good trends showing net erosion throughout this area	AIII-13
12	Steveston Bend (Fig.3B)	79 to 103	25	0.94	0.04	River-dominated transport is confined to the right bank of Steveston Bend. Within the channel there is a very "tight" counterclockwise gyre that starts as far east as Blair Point. The presence of this gyre terminates the Woodward Reach transport regime (10). The lines show a complex mix of X-distributions suggesting that erosion and deposition are in a delicate balance. The trend statistics for these lines are excellent. Lines could not be extended west of the Steveston jetty.	AIII-14
13	Roberts Bank Delta Foreslope (Fig.3B)	104 to 110	7	0.85	0.11	The only area in the offshore where sand samples are found below 50 m. Trends show mainly erosion and transport parallels the bathymetry in the flood tide direction (i.e., northwest).	AIII-16
14	Westshore Terminals Intertidal Flat (Fig. 3B)	111 to 115	5	0.80	0.22	A clockwise gyre originating from offshore sediments (Roberts Bank Delta Foreslope). Some erosion near low water.	AIII-17

15	Tsawwassen Terminal Intertidal Flat (Fig. 3B)	116 to 121	6	0.75	0.05	Similar to the Westshore Terminals Intertidal Flats (14). A clockwise gyre originating from offshore sediments (Roberts Bank Delta Foreslope). Some erosion near low water.	AIII-19
16	Southern Roberts Bank (Fig. 3B)	122 to 136	15	0.84	0.09	All lines originate in Canoe Passage and fan out over the southern half of Roberts Bank. Nearly all show a mixed case with deposition dominating over erosion.	AIII-20
17	Northern Roberts Bank (Fig. 3B)	137 to 149	13	0.83	0.14	These lines form a clockwise gyre originating at Sand Heads. Near the source, the lines show net accretion; farther away they show erosion.	AIII-22
18	Sturgeon Bank (Figs. 3B and 3C)	150 to 169	20	0.87	0.09	Transport is from Sand Heads towards the Iona Outfall. Sturgeon Bank receives its sediment from the South Arm and, similar to the Northern Roberts Bank regime, accretion occurs near the source. Lines farther away show a mixed case with erosion frequently dominating over accretion.	AIII-24
19	Iona Intertidal Flat (Fig.3C)	170 to 175	6	0.84	0.12	A slight clockwise gyre with all the lines showing net erosion. The North Arm does not appear to be contributing any sediment to this region.	AIII-26

TABLE 1B: SUMMARY OF THE SEDIMENT TRANSPORT ENVIRONMENTS IN THE FRASER RIVER/STRAIT OF GEORGIA (MUD).

• Transport Environment (See Figs.3A, 3B, and 3C)		Lines	No. of Sample Lines	R2 Values		Notes	Figure Numbers
				Mean	S.D.		(Appendix III)
1	Douglas Island	N/A	0	-	-	-	-
2	Coquitlam River/ Pitt River (Fig.5A)	1	1	0.85	-	This one line of samples shows net accretion of mud from the Fraser River into the Pitt River. It only partially agrees with the sand trends for this region.	AIII-27
3	Queen's Reach/ Sapperton Channel	N/A	0	-	-	-	-
4	Eastern North Arm (Figs.5A and 5C)	2 to 4	3	0.84	0.07	Line 2 shows total deposition occurring in the "Queens- borough Backwater". The remaining lines show net accretion in the downriver direction.	AIII-28-
5	South Mitchell Island	N/A	0	-	-	-	-
6	Middle Arm (Fig.5C)	5 to 7	3	0.89	0.11	All lines show net accretion in the downriver direction	AIII-29

7	Western North Arm (Fig.5C)	8 to 16	9	0.83	0.07	Downriver transport into the Strait of Georgia where trends turn to the north around Point Grey. Total deposition is occurring in McDonald Slough. The remaining trends are dominantly net accretion. Evidence for clockwise transport of mud from the river onto the booming grounds on the right bank inside the Point Grey breakwater.	AIII-30 AIII-31
8	City Reach/ Annacis Channel (Fig. 5A)	17 to 20	4	0.96	0.04	Total deposition occurring in Gunderson Slough and in Annacis Channel. Net accretion in the main river.	AIII-32
9,10,11,16	Gravesend Reach (Figs. 5A, 5B and 5C) Woodward Reach (Figs. 5B and 5C) Ladner Reach/ Canoe Passage/Sea Reach (Fig. 5B) Southern Roberts Bank (Fig. 5B)	21 to 40	20	0.85	0.08	This large group of lines encompasses the sand transport environments 9, 10, 11 and 16. All lines show net accretion with the exceptions of total deposition inside Deas Slough and Ewen Slough.	AIII-33 AIII-34
12	Steveston Bend	N/A	0	-	-	Lines from Steveston Bend and the Fraser River join the transport paths on the Delta Foreslope (#20)	-

13,14	Roberts Bank Delta Foreslope (Fig.5B) Westshore Terminals Intertidal Flat (Fig. 5B)	41 to 43	3	0.99	0.02	These three lines conform to the sand trends in Environments 13 and 14.	Too few samples for X-distribution
17	Northern Roberts Bank (Fig. 5B)	59 to 66	8	0.94	0.06	Net accretion on Roberts Bank with total deposition occurring near the fringe marsh. The transport paths follow the same clockwise gyre as determined for sand transport	AIII-35 AIII-36
18	Sturgeon Bank (Fig.5C)	67	1	0.84	-	This one line of samples conforms to the general pattern of transport over Sturgeon Bank for sand. The trend indicates dynamic equilibrium.	AIII-37
19	Iona Intertidal Flat	N/A	0	-	-	-	-
20	Delta Foreslope (Fig. 5B, 5C)	44 to 58	15	0.91	0.07	This environment has no sand environment counterpart. Nearly all the trends show net accretion in a north direction that parallels the bathymetry. Several mud samples from inside the Fraser River are shown to join the Delta Foreslope regime.	AIII-38

.5.0 DISCUSSION

5.1 General Considerations

5.1.1 Fraser River

In the Fraser River, the derived sediment transport patterns show, in general, net movement of both sand and mud from the upstream end of the study area to all the exits into the Strait of Georgia. Such a finding is hardly unexpected given the classic delta morphology associated with the river. A notable exception is the transport paths of Environment 2 (Coquitlam River/Pitt River) which indicates upstream movement of sediments towards Pitt River. The evidence for such movement is supplied by the formation of a "negative delta" at the south end of Pitt Lake the result of flood tide currents that are stronger than the combined ebb stream and river flow (Thomson, 1981).

Such reversals were determined in a number of localities that include, (1) Queen's Reach (south of City Bank), (2) Annacis Channel, (3) The channel south of Mitchell Island (Environment 5), (4) inside Steveston Bend and Steveston Cut, and (5) in nearly all backwaters (e.g. Deas and Gunderson Sloughs and Cannery Channel). Despite the large amount of literature concerned with the Fraser River, no specific evidence could be found to support directly any of these reversals. Nevertheless, the example of the Pitt River demonstrates that a sediment transport reversal is not only possible, but does in fact exist, and the sediment trend analysis is capable of determining its presence.

In some instances, the reversals coincide with areas requiring major dredging. Ferguson (1991), has identified the North Arm immediately east of Mitchell Island as one such region. Here, the South Mitchell Island transport regime meets the Eastern North Arm transport regime, thus providing conditions that should increase sedimentation. In Steveston Cut, there is a flow reversal that meets the Woodward Reach transport regime. When river transport dominates over flood transport, high deposition could be expected in Steveston Cut; when vice versa, the deposition would shift to Woodward Reach. A third region where, prior to the late 1960's, channel instability resulted in large amounts of dredging is in the Trifurcation area at New Westminster. In this region, downriver transport bifurcates into the North and South Arms, but is "hampered" by an opposing flow out of Annacis Channel. Since the construction of training walls, this area is now largely self-scouring.

Only in Queen's Reach, southeast of Sapperton Dike did the delineation of a flow reversal fail to predict an area of high deposition (see Environment 3, Table 1A). There is a dredge disposal site in this part of the river (PWC-7; Ferguson, 1991) and, according to F. Stepchuk (pers. comm.), this is an area used extensively for borrow dredging. Such activities could have two possible effects on the sediment trends. The first is that dredging and dumping have changed the natural sediment distributions sufficiently to produce trends that are erroneous. The second is that the activities, particularly the borrow

dredging, have actually caused a transport reversal in the main channel south of City Bank. The R^2 values for this transport environment are relatively high (0.86 ± 0.07; Table 1A) which favour the second explanation.

Other areas of high deposition are identified in St. Mungo Bend (although Ferguson, 1991, reported that since the construction of the Alex Fraser bridge, maintenance dredging has been much reduced), Tilbury Bend, and the end of the North Arm jetty. An accreting sediment transport regime was determined for each of these areas.

The region of greatest conflict between known areas of deposition and the transport paths is in stretch of river between Sand Heads and Woodward Reach. Seaward of Blair Point many of the trends were mixed, showing valid statistics for both erosion and deposition, a few were depositional and still others, particularly adjacent to the Steveston jetty, were erosional. In Woodward Reach, all the trends were erosional. Earlier in this discussion, it was suggested that the confluence of opposing transport regimes should result in areas of high deposition. The lack of depositional trends cannot easily be explained although they do show evidence for preferred erosion on the right bank of Steveston Bend and accretion on the left, a finding substantiated by Kostachuk and Luternauer (1987). Possibly a combination of large amounts of dredging in these channels as well as the presence of a dredge disposal site (PWC-3; Ferguson, 1991) in Woodward Reach have resulted in erroneous X-distributions, despite the fact that the trend statistics, particularly those for Steveston Bend, are excellent (Table 1A) [12].

5.1.2 Tidal Flats

Of the four tributaries that enter the Strait of Georgia, only two, Middle Arm and Canoe Passage, have a relatively unobstructed flow onto the tidal flats. Canoe Passage accounts for 14% of the total Fraser River discharge (Acres, 1984; Hay,1988), and the pathways for sand produce a dendritic pattern of transport (Environment 16; Southern Roberts Bank) that could be considered "typical" of a meandering transport regime across a delta tidal flat. Through Canoe passage itself, the trends are indicative of high energy, erosive transport, and on the delta flat, nearly all the trends produced a mixed case (i.e., both deposition and erosion). The statistics nearly all favour deposition, but the mix of the two cases, and the eroding trends in Canoe Passage, provide a signal that there may be a limited quantity of sediment reaching this area. Should sediment supply decrease in the future, the tidal flat in this area might easily change to net erosion.

Middle Arm accounts for a much smaller volume of discharge (probably around 3% or 4%). Again, the amount of sediment may be small as eroding trends occur inside Middle Arm and there appears to be no transport of sediment actually out of the Arm onto Sturgeon Bank.

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[12] A further possibility for the uncertainty in these results may be due to dredging of the south bank to provide material for the construction of an underwater berm on the north side of Steveston Bend (F. Stepchuk, Canadian Coast Guard, pers. comm.). However, since this happened in 1991, it is unlikely that these effects could still be apparent in such a highly dynamic environment.

The remaining two tributaries, North Arm and South Arm, have been completely channelized across the tidal flats, with the result that the dendritic transport patterns observed out of Canoe Passage cannot exist (Monahan et al., 1993, make a very similar conclusion). In both Arms, sand is carried to the extreme seaward edge of the tidal flats. In South Arm, which carries 70% of the Fraser River discharge, the sediment trends indicate three routes for sand to take. The first is a return system down the south side of Steveston Channel which suggests that there is a constant recycling of sand in this region. The second route follows a clockwise gyre over Northern Roberts Bank (Environment 17), and the third transports sand northeast across Sturgeon Bank (Environment 18). Patterns of megaripples on Sturgeon Bank provide some support for the latter transport direction (Medley and Luternauer, 1976).

There are distinct similarities in the transport of sediment on North Roberts Bank and Sturgeon Bank. For the transport pathways close to the Sand Heads source, the trends show net accretion. Farther away from source, the lines become either mixed case, or produce X-distributions indicative of net erosion. Similar to the findings on Southern Roberts Bank, the amount of sediment available for deposition appears to be small. Accretion is occurring near source, but the trends soon show evidence for erosion.

There may be a fourth route for sand to be removed from the Sand Heads region, although it was not apparent from the samples obtained for the trend analysis. Evoy et al., (1993) described downslope slumping and gravity flow processes as a mechanism for sand to bypass the delta slope and to be deposited directly in prodelta and basinal environments. Sand lost from the river mouth in this way will no longer be available for deposition on the tidal flats.

Similar to the South Arm distributary, sand out of the North Arm does not appear to be transported onto the delta foreshore (no sand samples were found in the sampling program). In this case, trends terminated at the Point Grey breakwater, and no further transport could be determined from the North Arm onto any of the tidal flats.

Environment 19 (Iona Intertidal Flat) appears to be part of the Sturgeon Bank transport regime; however, the pathways required a "new start" at the Iona Outfall. Possibly at this point the outfall is providing a small amount of new source material. The directions of transport are supported by patterns of megaripples (Medley and Luternauer, 1976). All the trends show net erosion that is consistent with the distance from the main source of sand at Sand Heads.

The Westshore Terminals Intertidal Flat (Environment 14) and the Tsawwassen Terminal Intertidal Flat (Environment 15) appear to have no relationship with sediments derived from the Fraser River. The transport patterns show clockwise gyres with a sediment source from a northwest-trending nearshore regime. The trends for lines close to the low water line indicate net erosion suggesting, once again, that there is little sediment available to maintain the present intertidal width.

5.1.3 Nearshore and Offshore

All trends on the delta foreslope show transport to the north parallel to the bathymetry, a finding in complete agreement with known processes. North flood currents are stronger than the ebb (Pickard, 1956), and even surface currents affecting dispersal of the Fraser River plume favour northward transport (Thomson, 1981). According to Luternauer et al., (1978), bottom currents on the foreslope are strong enough to transport sand-sized material and hydraulic bedforms have been observed on the sandy southwestern Roberts Banks slope (Environment 13; Roberts Bank Delta Foreslope). The sediment trends for these sands show net erosion which is supported by observations made in a PISCES submersible revealing erosional ledges and lag deposits (Luternauer and Finn, 1983). Kostaschuk and Luternauer (1993) point out that there is no obvious source of sand replenishment and warn of slope failure. The trends indicate that the sand source must be the erosion of earlier deposits of delta foreslope sands, and it appears that such a process could have dangerous consequences to the stability of the Tsawwassen and coal port terminals[13].

The presence of the Fraser River and its associated plume are undoubtedly responsible for the mud deposits on the foreslope in depths of > 50 m. It is not, however, primarily the cause for the northward direction of transport. Rather, particulate matter in the plume is carried both north and south of the outflow source at Sand Heads. On settling through the pycnocline, these particles become deposited from the transport regime that is under the influence of the dominant northward currents.

5.2 Implications to Dredging

In general terms, the patterns of sediment transport as determined by the trend analysis provide a clear indication that the sand portion of the Fraser River is no longer having a significant role in either the maintenance or "normal" growth of the delta. The trends in the lower river and on the delta flats supply considerable evidence that deposition and erosion are presently often in a "fragile" balance, an indication that sediment supply is frequently insufficient for net accretion. The sampling required to do this study revealed very little sand below the 50 m water depth on the delta foreslope (Fig. 2), yet cores of earlier foreslope deposits contain abundant sand (Luternauer et al., 1993).

It is almost impossible not to conclude that sand removal by dredging in the river, together with channelization of the main distributaries, is the primary cause for the lack of sand replenishment on the tidal flats. With the exception of sediment transport out of Canoe Passage, all the sand available to maintain Sturgeon and Roberts Banks must first reach Sand Heads and then be redistributed by littoral processes back over the intertidal flats. The fact

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[13] It is again emphasized that the trend analysis is unable to determine the rate of this erosion. This finding of erosion on the foreslope in front of the terminals is exacerbated by the present inability of the Fraser River to supply sediments to this area. It is recommended that studies should be undertaken specifically to determine the present rates of erosion in order to assess the degree of danger to the terminals.

that the transport regime changes from accretion to erosion with distance from the Sand Heads source provides a warning that areas of the intertidal flats are becoming starved of sand. Any decrease of sand reaching Sand Heads will result in increasing erosion or, quite possibly, a change of sediment type (i.e., to mud).

The statistics of sand removal from the river and the consequent lowering of the river bed are impressive. According to Public Works Canada (1989), only about 40% of the bed load (i.e., sand) entering the river at Mission reaches Sand Heads. Of this amount, it is unknown how much is recirculated back into Steveston Channel, or how much is lost to the lower slopes of the delta through mass wasting events. Bed levels within the navigation channels are known to have lowered steadily since 1950 at a rate of about 8 cm y^{-1} (McLean and Tassone (1991). Model experiments in Germany that were confirmed in a recent GeoSea study [14] have shown how the effects of channel deepening actually increase tidal range which, in turn, serves to force more sediment upstream (Jenson and Sieffert, 1994). It may be that continual upriver deepening of the channel is responsible for increasing the landward return of sediment into Steveston Channel. The fact that in recent years, the amount of dredging has nearly doubled merely to maintain bed levels at Sand Heads and Steveston Cut (Public Works Canada, 1989; B. Tassone, Environment Canada, pers. comm.) strongly supports the concept of an increasing landward return of sediments [15].

This finding may be applicable in the proposed re-design of the Steveston Bend training wall. The current plans are to install bendway weirs to decrease sedimentation on the south bank (F. Stepchuk, PWCGS, pers. comm.). Such a plan assumes a unidirectional flowing river. If, however, deposition on the south bank is primarily the result of flood currents, the effect may be to "drive" sediment farther up-river.

As discussed above, the only portion of the tidal flats that appears to be still influenced by "normal" deltaic processes is the southern Roberts Banks area. Here, sediment transport out of Canoe Passage forms a dendritic transport pattern that might be expected over delta topset beds. Compared to the main channel from Steveston to Sand Heads, the distance to the low water line through Canoe Passage is nearly 2 km shorter (i.e., the slope of the intertidal flat is steeper at Canoe Passage than at the South Arm). As a result, it is likely that Canoe Passage is under pressure to become the principal discharge channel of the Fraser River rather than its present channel past Steveston. Pressure for the main flow of the river to discharge through Canoe Passage

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[14] The sediment transport regime of the Ems River; unpublished GeoSea report (April, 1992) for the Bundesanstalt für Wasserbau, Hamburg, Germany.

[15] According to Fred Stepchuk (Canadian Coast Guard, pers. comm.), the increased dredging in Steveston Bend, Sand Heads and particularly Steveston Cut was implemented because of a change in the management strategy for the dredging program.. This strategy is to overdredge in the navigation channel to eliminate intrusion of bed waves into the channel during freshet. F. Stepchuk also believes that the landward return of sediments into Steveston Channel may be insignificant relative to the deposition of sediment during freshet, in terms of impacts to navigation.

will also be enhanced by the present erosion of the foreslope adjacent to the coal terminal [16].

A further source of pressure to change the position of the main channel would be the continued growth of the delta at Sand Heads. While the mud deposits of the lower foreslope (below 50 m) are known to be advancing at about 8.5 m y^{-1} (Mathews and Shepard, 1962; Stewart and Tassone, 1989), the growth of sand in the upper foreslope is more difficult to evaluate due to dredging and dumping activities. Mathews and Shepard (1962) recognized that "growth of the outer slopes of the delta front may be continuing apace while growth of the upper slopes, where sand deposition plays a much more important part, may be significantly retarded as a result of human activities". Dredging in the river, therefore, may be providing a possible benefit by decreasing natural delta growth at Sand Heads and thereby alleviating some of the pressure of a major channel re-routing.

At present, the emphasis in river control has been to avoid the main flow of the river to discharge through Canoe Passage (F. Stepchuk, pers. comm.). There may be, however, several reasons to examine this option with the following points in mind. First, if the river naturally wants to shift, engineering control will become increasingly expensive and may ultimately fail anyway. Second, a straight channel across the tidal flats from Canoe Passage would be shorter and dredging maintenance correspondingly less. Third, the steeper slope across the tidal flats would inhibit the extensive deposition now occurring in the Steveston Channel; and fourth, the foreslope of the delta at this locality is apparently eroding, and may be threatening the safety of the coalport and Tsawwassen terminals. The change in river outflow would undoubtedly increase sedimentation where it is needed.

5.2.1 Proposed Dredge Material Disposal Sites

The transport patterns may be used to determine potential dredge disposal sites with the view to provide maximum engineering and environmental advantages. Given that sediment transport out of the North Arm is evidently "weak", and that there is already a sediment return system operating in the South Arm, there can be little reason to recommend any preferred location in the river itself [17]. Therefore, three sites are selected outside the river. Each site, if it is to be considered for use, would require specific process studies both to refine the location and to determine optimum delivery rates to avoid unforeseen consequences. It should be noted that economic or political

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[16] It is believed by F. Stepchuk (Canadian Coast Guard, pers. comm.) that without training works to restrain the river, there is a possibility of Canoe Passage becoming the next main channel of the Fraser River. In the last decade there has been a major change in engineering thinking from that of using "might" to control nature to that of attempting to understand how to work within the bounds imposed by nature. The former seldom works in the long term (see, for example, an account of the effects of training works to control the Mississippi delta by McPhee, 1989). Acceptance and implementation of the latter, on the other hand, may result in nature aiding in the solution to engineering problems and incalculable cost savings.

[17] Depending on transport patterns during the freshet, there may be other times of the year when river disposal might be desirable.

considerations have not been taken into account. These localities are as follows (Fig. 7):

Site 1: This disposal site is placed at the "upstream end" of the Roberts Bank Delta Foreslope transport environment. Its purpose is to replenish the eroding foreslope with sand in order to decrease the possibility of undercutting and mass wasting events that may be causing a hazard to the coal port and Tsawwassen terminals [18]. Replenishment of sand in this area will also have the indirect effect of helping to maintain Canoe Passage as a minor, secondary channel (i.e., erosion and steepening of the foreslope in this area will increase the pressure on Canoe Passage to become the main river outlet).

Site 2: This disposal site is located on the eroding transport paths found in Environment 17 (Northern Roberts Bank). It is placed in order to maintain sand on Roberts Bank that would ordinarily be deposited by a meandering South Arm Channel.

Site 3: Similar to Site 2, Site 3 is designed to maintain sediments on Sturgeon Bank. It is located along the low water line and is designed to allow sediment to be transported across the bank following pathways that, at present, appear to be in some danger of eroding[19].

5.3 Implications for Contaminant Transport

The relationships between contaminants and sediment transport pathways were first determined in a study by McLaren and Little (1987). Similar findings have been observed in a variety of environments, including Liverpool Bay and the Bristol Channel in the U.K., Sullom Voe in the Shetland Islands, Howe Sound on the west coast of Canada (McLaren, Cretney, et al., 1993), and in Vancouver Harbour [20]. These may be summarized as follows:

(1) Given a greater surface area and more sites available for adsorption, contaminants have a greater association with fine sediment (silt and clay) than with coarse sediment (sand).

(2) Sediments in dynamic equilibrium (Fig. A-5,A; Appendix I) show no relationship between contaminant loadings and distance along the transport path.

(3) In environments undergoing net accretion (Fig. A-5,B; Appendix I) there is a general linear increase of contaminant loading along the transport path.

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[18] Personnel at the Geological Survey of Canada do not believe sediment disposal in this area is desirable for two reasons. They believe disposal operations will increase the instability of the foreslope. They also feel that its location in the United States would preclude Canadians from using it as a disposal site anyway. It is re-emphasized that these recommendations are made assuming detailed site surveys do not otherwise exclude their use, and without political considerations.

[19] This site is in close proximity to the Greater Vancouver Regional District's (GVRD) Iona Island Wastewater Treatment facility's deep sea outfall study area and therefore the disposed dredge materials may affect this GVRD program.

[20] Sediment transport in Vancouver Harbour: implications to the fate of contaminated sediments and/or dredged material disposal; GeoSea report to the Burrard Inlet Environmental Action Program, 1994.

Because sediment transport is the cause of concentrating contaminants in the environment, the specific relationship between contaminants and their sources can be lost.

(4) Contaminant loadings decrease rapidly along an eroding transport path (Fig. A-5,C; Appendix I).

(5) In environments of total deposition (Fig. A-5,D; Appendix I), contaminants are found as localized "highs" that can generally be associated with a specific source.

(6) When the X-distribution is horizontal, all particles, whether contaminated or not, have an equal probability of deposition. There is not, therefore, any preferred area for the deposition of contaminants and more or less constant concentrations are to be expected throughout such an environment [21].

From the findings of the sediment trend analysis, the following points can be made:

(1) In the main channels of the river, the dominance of highly mobile, sandy sediments precludes a useful monitoring program. While contaminant levels could be high by virtue of a nearby source, or random amounts of fine material, the changes in contaminant loadings are expected to be rapid and variable. Such variability will probably be too great to achieve meaningful longterm data.

(2) All backwaters are expected to be sites of contaminant accumulation (e.g. Gunderson Slough, Deas Slough, "Queensborough Backwater", Ewan Slough and McDonald Slough) an observation supported by data in Stancil (1980). In these environments, mud deposits are generally the result of total deposition and, as such, specific sites of "contaminant highs" can be expected. Ordinarily, backwaters would be ideal sites to obtain cores for establishing the long-term history of river contamination and to provide baseline data for continued monitoring. Surface sediments collected at regular time intervals should reflect the "health" of the river as a whole and establish the efficacy of contaminant source control.

Unfortunately, many of the backwaters are dredged on an irregular basis (Ferguson, 1991), and care should be taken to locate undisturbed sites for coring and regular surface-sediment monitoring. For the purposes of this report, any or all of the backwaters showing total deposition (Figs. 6A, 6B, and 6C) should be considered for environmental monitoring, provided undisturbed localities can be both determined and maintained (Fig.7).

(3) Annacis Channel is the longest stretch of river channel where mud is totally deposited. Therefore, specific contaminant highs can be expected. A sampling program in Annacis Channel could be designed to discover their location(s), and either a cleanup or monitoring program instigated (Fig.7).

(4) Contaminant levels are expected to increase down all accreting transport pathways determined for muddy sediments (Figs. 6A, 6B, and 6C). These include the North Arm and it's Booming Ground, Middle Arm, Cannery Channel, Ladner and Sea Reach, the South Arm (very few mud samples)

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[21] No X-distributions of this type were determined in this study.

Canoe Passage, and the delta foreshore below 50 m. Of these, the simplest monitoring locality is the eastern end of Cannery Channel (Fig.7). This site has been selected because it is one of the few localities associated with the river where there is net accretion of mud, and little or no sand present in the environment.

(5) Contaminants in the sediments associated with the former Iona Outfall (prior to the construction of an offshore pipe) appear to be at a location where they can not easily "escape" from the region between the outfall and the "Sea Island Jetty" (Stancil, 1980).

(6) On the delta foreslope, contaminated particles discharged in the Fraser plume will, on breaking through the pycnocline, be transported to the north. The accreting transport regime indicates that contaminant levels are likely to increase from south to north. Beyond the foreslope (where no samples were taken), it is likely that X-distributions will become increasingly horizontal, and the level of contaminants contained in these sediments will show little variability.

To assess contaminant levels on the foreslope, it is suggested to sample along a specific bathymetric contour that parallels the whole delta front (Fig.7). Samples could be collected at 1 to 2 km intervals, and the findings should provide, not only a better understanding of the contaminant behaviour with transport, but most importantly, a regular monitoring program will reflect changing conditions for the whole of the Fraser River. The precise depth of the sample line should be determined by first sampling down the slope at various localities and selecting a depth where contaminant concentrations are highest.

6.0 SUMMARY AND CONCLUSIONS

(1) A sediment trend analysis was performed on about 1500 samples collected from the lower Fraser River and its delta. Patterns of sediment transport were derived for two separate sediment types; (i) sand, including muddy sand, and (ii) mud, including sandy mud. Each sediment type produced similar patterns of transport, thus mutually supporting their validity.

(2) Both sand and mud are generally moved downriver. Compared to sand, very little mud is present in the river or on the intertidal flats; rather it is carried in the Fraser River plume where much of it is deposited on the delta foreslope below 50 m. The trends indicate that mud is accreting northwards along the pathways parallel to the bathymetry, a finding that is fully supported by various process studies. In the river, mud is found most often in backwaters where total deposition is occurring.

(3) Sand transport is, at several places, in an upriver direction, notably in Pitt River, Queen's Reach south of City Bank, Annacis Channel, the channel south of Mitchell Island and the south side of Steveston Channel. In most of the locations where a sediment transport reversal occurs, there is an associated region of high deposition where dredging is regularly undertaken.

(4) The patterns of transport show that most of the intertidal flats are not receiving sand through "normal" deltaic processes. Two of the four distributaries are channelized to the seaward edge of the intertidal flats (North and South Arms) and are restricted from meandering. The North Arm is not contributing any sediments to the Banks, whereas a portion of the sand that reaches the end of the South Arm (Sand Heads) is transferred to both Roberts and Sturgeon Banks by littoral processes. The remaining sand is either returned to Steveston Channel or removed to the offshore by mass wasting processes. There appears to be insufficient sand passing through Middle Arm to have any impact on Sturgeon Bank. Canoe Passage, on the other hand, is providing sand to the southern half of Roberts Bank in the only area of the delta that exhibits a pattern of transport to be expected on a delta. Intertidal sediments between the Causeways have no longer any relationship with the Fraser River sediments.

(5) There is much evidence to suggest that the amount of sand available either to replenish or to maintain the intertidal flats is not large. Many of the trends in the river, as well as those associated with Canoe Passage, show both erosion and deposition indicating a fine balance between the two. The trends across the north half of Roberts Bank and Sturgeon Bank show net accretion close to the sediment source at Sand Heads; however, farther away from this source, the trends change to mixed case (i.e., both erosion and accretion) and erosion only. The paucity of sand is further emphasized by its absence over most of the delta foreslope. Core data show that the deposition of sand was more common in the past.

(6) The only locality where sand is presently found below 50 m on the delta foreslope is in the south portion of the study area opposite the Westshore and Tsawwassen Terminals. Sediment transport is northwards, paralleling the bathymetry and the trends indicate net erosion. The only source for this sand

is the eroding foreslope sediments themselves, and continued erosion may well result in unstable conditions for the terminals. There appears to be a need for further work to assess the level of seriousness for this potential hazard.

(7) The evident lack of sand reaching the intertidal flats and the foreslope is attributed to the channelization of the South and North Arms, to dredging in the river, and to a lesser extent to the various causeways and jetties that traverse the Banks. Frequently more than half of all the sand dredged from the Fraser River is entirely removed for aggregates. Most of the rest is disposed of on the foreslope, thereby removing it from intertidal deposition altogether. It has been shown in other estuaries that a major consequence of dredging is to lower the level of the river bed and decrease the height of low water (i.e., the tidal range is increased) thereby encouraging upriver transport of sediment. The trend analysis suggests that this may be occurring throughout much of the length of Steveston Channel where dredging has generally increased just to maintain present bed levels. The transport patterns show that sand can be returned from Sand Heads to be deposited upstream at least as far as Blair Point. Unfortunately it is unknown if a landward return of sediments can occur during the freshet.

(8) Given that a landward return of sand is possible and may be partly responsible for the dredging requirements in Steveston Channel, remedial engineering works should be designed to discourage flood directed deposition.

(9) The transport patterns suggest that deposition will be high in Steveston Cut when river flow dominates over the flood (most likely during the freshet). When conditions are the opposite, deposition will be high in Woodward Reach.

(10) Removal of sand from the river may be having the beneficial effect of inhibiting delta growth at Sand Heads. Should the delta continue to grow at this location, the result will be to increase the pressure for the South Arm to make Canoe Passage its primary channel (i.e., the new route is shorter and steeper). Foreslope erosion opposite Canoe Passage will also contribute to the pressure for the river to use this route. Training structures are presently in place to help prevent such an occurrence from happening.

(11) It is suggested for several reasons that allowing the main channel of the river to flow through Canoe Passage might be given consideration. Using progressively larger and more costly engineering works to control a natural river shift may, in the long term, have more disbenefits than benefits. A channel across the tidal flats at Canoe Passage would be shorter resulting in a decrease of dredging activities, and the steeper slope might decrease the rate of deposition. Finally, such a route might increase deposition over the portion of the delta foreslope that is known to be eroding and provide protection for Tsawwassen and Westshore terminals.

(12) The trend analysis strongly suggests that large areas of the tidal flats are in a delicate balance between erosion and deposition. It is recommended that any further decrease of sand arriving at Sand Heads should be avoided. The result would probably be to decrease the replenishment of sand on the tidal flats causing either erosion or a change of sediment type to more muddy deposits.

(13) In an attempt to maximize engineering and environmental benefits, three new disposal sites are suggested to mitigate the erosion of the foreslope of Southern Roberts Bank and to maintain sedimentation on northern Roberts Bank and Sturgeon Bank.

(14) Sites to monitor for contaminants have been chosen in backwaters where mud is totally deposited. Care should be taken to select only areas where dredging will not disturb a longterm monitoring program. Cores taken in such localities should provide a "contamination history" of the river. It is suggested that a monitoring program on the delta forefront would provide an excellent basis for assessing the health of the whole Fraser River, as well as to establish the effects of the northward transport regime in driving contaminated sediments towards Burrard Inlet.

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8.0 REFERENCES

Acres, 1984: Fraser River, North Arm flow change impact study; prepared for Public Works Government Services Canada.

Ages, A., and Woolard, A., 1976: The tides in the Fraser River estuary; Environment Canada, Institute of Ocean Sciences, Sidney, British Columbia, Report 76-5, 100 p.

Ashley, G.M., 1977: Sedimentology of a freshwater tidal system, Pitt River - Pitt Lake, British Columbia; unpubl. Ph.D. Thesis, University of British Columbia.

Black, K.P. and Barnett, A.G., 1988: Sediment transport modeling under tidal flows with applications in a natural estuary; LAHR Symposium on Mathematical Modeling of Sediment Transport in the Coastal Zone. Proceedings. Copenhagen, May 30 - June 1, 1988, 5-13.

Church, M., et al., 1990: Channel stability and management of lower Fraser River Field Excursion Guide; Environment Canada, Inland Waters Directorate, Water Resources Branch, April, 1990.

Clague, J.J., Luternauer, J.L., and Hebda, R.J., 1983: Sedimentary environments and postglacial history of the Fraser River delta and lower Fraser valley, British Columbia: Canadian Journal of Earth Sciences, Vol. 20, 1314-1320.

De Meyer, Ph. and Wartel, S., 1988: Relation between superficial sediment grainsizes and morphological features of the coastal ridges off the Belgium coast; in: De Boer, P.L., et al. (eds), Tide Influenced Sedimentary Environments and Facies, Dordrecht, Riedel, 91-100.

Evoy, R.W., Moslow, T.F., Patterson, R.T., and Luternauer, J.L., 1993: Patterns and variability in sediment accumulation rates, Fraser River delta foreslope, British Columbia, Canada; Geo-Marine Letters, Vol.13, 212-218.

Ferguson, A., 1991: Navigation, dredging and environment in the Fraser River Estuary; prepared for: Fraser River Estuary Management Program, Navigation and Dredging Workgroup; Government of Canada and Province of British Columbia, 89 p.

GeoSea Consulting (Canada) Ltd., 1994: Sediment grain size analyses of sediment samples from the Fraser River, British Columbia. Data report and Appendix 1; Report and disk to: Environment Canada,

224 West Esplanade, North Vancouver, BC., V7M 3H7. Attn. T. Tuominen.

Hay and Company, 1988: Fraser River dredging, subgrade analysis. Prepared for Canadian Coastguard.

Jenson, J., and Sieffert, W., 1994 (in press): Water level changes in tidal estuaries due to deepening of navigation channels and sea level variations; International Symposium on Water Resources Planning in a Changing World, June 28-30, 1994, Carlsruhe, Germany.

Johnston, W.A., 1921: Sedimentation of the Fraser River delta; Geological Survey of Canada, Memoir 125, 46p.

Kostaschuk, R.A., and Luternauer, J.L., 1987: Large-scale sedimentary processes in a trained, high-energy, sand-rich estuary: Fraser River delta, British Columbia; in Current Research, Part A, Geological Survey of Canada, Paper 87-1A, 727-734.

Kostaschuk, R.A., and Luternauer, J.L., 1993: Preliminary measurements of subtidal dune migration and sediment movement on Roberts bank, Fraser River delta, British Columbia; in Current Research, Part E; Geological Survey of Canada, Paper 93-1E, 67-72.

Little, D.I., and McLaren, P., 1989: Sediment and contaminant transport in Milford Haven, Wales; in: Ecological Impacts of the Oil Industry, B. Dicks ed., John Wiley & Sons, 203-234.

Luternauer, J.L., Clague, J.J., Hunter, J.A.M., Pullan, S.E., Roberts, M.C., Woeller, D.J., Kostaschuk, Moslow, T.F., Monahan, P.A., and Hart, B.S., 1993: The Fraser River Delta; architecture, geological dynamics and human impact: reprinted from Deltas of the World, Proceedings, 8th Symposium on Coastal and Ocean Management, ASCE, July 19-23, 1993, Now Orleans, Louisiana, 99-113.

Luternauer, J.L., 1980: Genesis of morphologic features on the western delta front of the Fraser River, British Columbia - status of knowledge: in The Coastline of Canada, S.B. McCann, editor; Geological Survey of Canada, Paper 80-10, 381-396.

Luternauer, J.L., and Finn, W.D.L, 1983: Stability of the Fraser River delta front; Canadian Geotechnical Journal, Vol.20, 603-616.

Luternauer, J.L., Swan, D., and Linden, R.H., 1978: Sand waves on the southeastern slope of Roberts Bank, Fraser River Delta, British Columbia; in Current Research Part A, Geological Survey of Canada, Paper 78-1A, 351-356.

Mathews, W.H. and Shepard, F.P., 1962: Sedimentation of the Fraser River delta; Bulletin of the American Association of Petroleum Geologists, Vol.46, 1416-1463.

McLaren, P. and Bowles, D., 1985: The effects of sediment transport on grain-size distributions. Journal of Sedimentary Petrology, Vol. 55, 457-470.

McLaren, P and Little, D., 1987: The effects of sediment transport on contaminant dispersal: an example from Milford Haven. The Marine Pollution Bulletin, Vol. 18, 586-594.

McLaren, P., Collins, M.B., Gao, G., and Powys, R., 1993: Sediment dynamics of the Severn Estuary and inner Bristol Channel; Journal of the Geological Society, London, Vol. 150, 589-603.

McLaren, P., and Powys, R., 1989: The use of sediment trends to assess the fate of dredged material; Proceedings of WODCON XII, World Dredging Congress, Orlando, Florida, USA, 2-5 May, 1989, 223-233.

McLaren, P., Cretney, W.J., and Powys, R., 1993: Sediment pathways in a British Columbia Fjord and their relationship with particle-associated contaminants; Journal of Coastal Research, Vol. 9, 1026-1043.

McLean, D,G. and Tassone, B.L., 1991: A sediment budget of the lower Fraser River; Proceedings, 5th Federal Interagency Sedimentation Conference, March 18-21, Las Vegas, Nevada, 1991, 2-33 to 2-40.

McLean, D.G., and Church, M.A., 1986: A re-examination of sediment transport observations in the lower Fraser River; Environment Canada, Water Resources Branch, Inland Waters Directorate, Sediment Survey Section, IWD-HQ-WRB-SS-86-6.

McPhee, J., 1989: The control of nature; The Noonday Press, New York, 272 p.

Medley, E., and Luternauer, J.L., 1976: Use of aerial photographs to map sediment distribution and to identify historical changes on a tidal flat; Report of Activities, Part C, Geological Survey of Canada, Paper 76-1C, 293-304.

Monahan, P.A., Luternauer, J.L., and Barrie, J.V., 1993: A delta topset sheet sand and modern sedimentary processes in the Fraser River delta, British Columbia; in Current Research, Part A, Geological Survey of Canada, Paper 93-1A, 263-272.

Neu, H.J.A., 1996: Proposals for improving flood and navigation conditions in the lower Fraser River; Unpublished manuscript, (Library, Institute of Ocean Sciences), 79p.

Norecol Environmental Consultants Ltd., 1993: Recommended Guidelines for Wastewater Characterization in the Fraser River Basin. Prepared for Environment Canada, Fraser Pollution Abatement Office, North Vancouver, B.C., 67p.

Pickard, G.L., 1956: Surface and bottom currents in the Strait of Georgia; Journal of Fisheries Research Board of Canada, Vol.13, 581-590.

Public Works Canada, 1989: Effects of dredging on Fraser River channel regime; Unpublished report by D.G. McLean and B.L. Tassone, Environment Canada, #883-578, 25p.

Stancil, L.G., 1980: Industrial effluents; Fraser River Estuary Study, Water Quality; Background report of the Water Quality Work Group to the Fraser River estuary study of the Fraser River Estuary Study Steering Committee. Co-published by the Government of Canada, Province of British Columbia, Victoria, B.C., 187p.

Stancil, D.E., 1980: Aquatic biota and sediments; Fraser River Estuary Study, Water Quality; Background report of the Water Quality Work Group to the Fraser River estuary study of the Fraser River Estuary Study Steering Committee. Co-published by the Government of Canada, Province of British Columbia, Victoria, B.C., 187p.

Standing Committee on the Fraser River Estuary Water Quality Plan, 1990: Status report on water quality in the Fraser River estuary; Fraser River Estuary Management Program, New Westminster, B.C.

Stepchuk, F., Canadian Coast Guard, Personal Communication.

Stewart, I. and Tassone, B., 1989: The Fraser River delta: a review of historic sounding charts; Environment Canada, Conservation and Protection, Vancouver, B.C., 39p.

Swain, L.G., 1980: Industrial effluents; Fraser River Estuary Study, Water Quality; Background report of the Water Quality Work Group to the Fraser River estuary study of the Fraser River Estuary Study Steering Committee. Co-published by the Government of Canada, Province of British Columbia, Victoria, B.C., 195p.

Thomson, R.E., 1981: Oceanography of the British Columbia coast; Canadian Special Publication of Fisheries and Aquatic Sciences, 56, Department of Fisheries and Oceans, 291 p.

Van Heuvel, T., McLaren, P., and Powys, R., 1993: Sediment transport pathways in the Eems Estuary, The Netherlands; Proceedings of the 1993 Canadian Coastal Conference, May 4-7, 1993, Vancouver, British Columbia, 167-176.

Vermeer, K., and Butler, R.W., 1987: The ecology and status of marine and shoreline birds in the Strait of Georgia, British Columbia; Proceedings of a Symposium sponsored by the Pacific Northwest Bird and Mammal Society and the Canadian Wildlife Service, Sidney, BC. 11 Dec. 1987; Canadian Wildlife Service, Special Publication.

APPENDIX I

Sediment Transport Model

1.0 SEDIMENT TRANSPORT MODEL

The following is a brief review of the transport model, a detailed analysis of which is contained in McLaren and Bowles (1985).

1.1 Case A (development of a lag deposit)

Consider a sedimentary deposit which has a grain-size distribution denoted by the function g(s) (Fig. A -1). where 's' is grain size in phi units. 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:

$$r(s_i) = kg(s_i)\,t(s_i) \qquad (1)$$

or

$$t(s_i) = \frac{r(s_i)}{kg(s_i)}$$

where $g(s_i)$ and $r(s_i)$ define the proportion of the sediment in the ith grain-size class interval for each of the sediment distributions.

k is a scaling factor that normalizes r(s) so that:

$$\sum_{i=1}^{N} rs_i = 1$$

thus

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

With the removal of r(s) from g(s) the remaining sediment (a lag) has a new distribution denoted by d(s) (Fig. A -1) where :

$$d(s_i) = kg(s_i)[1 - t(s_i)]$$

or

$$t'(s_i) = \frac{d(s_i)}{k'g(s_i)}$$

where

$$t'(s_i) = 1 - t(s_i)$$

and

$$k' = \frac{1}{\sum_{i=1}^{N} g(s_i)[1 - t(s_i)]}$$

The function, t(s), is defined as a sediment transfer function and is described in exactly the same manner as a grain-size distribution function. 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 during a unit of time.

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 shape are termed low energy and high energy transfer functions respectively (Fig. A -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 g(s) (Fig. A -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).

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) (Fig. A -1). The function 1 - t(s) is, therefore, positively skewed, with the result that d(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) an infinite number of times (i.e. 'n' times), then the variance of both g(s) and d(s) will approach zero (i.e. sorting will become better). However, depending on the initial distribution of g(s), it is possible for variance to become greater before eventually decreasing. Because the phi scale produces approximately Gaussian or normal distributions which are symmetrical, it is probable that an increasing variance will rarely be observed.

Given two sediments, $d_1(s)$ 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 similar (Case A; Table A -1).

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 the sediment in transport (Fig. A -3). Each deposit is derived from its corresponding sediment in transport, and according to the '3-box' model shown in Figure A -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 :

$$d_2(s) = kd_1(s)X(s)$$

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

or $$X(s) = \frac{d_2(s)}{kd_1(s)}$$

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

$$d_2(s) = \frac{kd_1(s)t_1(s)[1-t_2(s)]}{1-t_1(s)}$$

$$= kd_1(s)X(s) \qquad (2)$$

where $$X(s) = \frac{t_1(s)[1-t_2(s)]}{1-t_1(s)} \qquad (3)$$

The function X(s) combines the effects of two transfer functions $t_1(s)$ and $t_2(s)$ (Equation 3). 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 over the period of time represented by the samples. The deposit $d_2(s)$ will, therefore, change relative to $d_1(s)$ in accordance 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 3. It is important to note that X(s) can be derived from the deposits themselves (Equation 2) and it provides the relative probability of any particular sized grain being moved.

Using empirically derived t(s) functions it can be shown that when energy is decreasing in the direction of transport [i.e. $t_2(s) < t_1(s)$] and both are low energy functions (Fig.A-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, $d_1(s)$ and $d_2(s)$ and $d_2(s)$ 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 A -1).

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

In the event that $t_1(s)$ is a high energy function (Fig. A-2), and $t_2(s) < t_1(s)$ (i.e. energy is decreasing in the direction of transport), the result of Equation 3 will produce a positively skewed X(s) distribution (Fig. A-4). Therefore, $d_2(s)$ will become coarser, better sorted and more positively skewed than $d_1(s)$ in the direction of transport, and should this relationship be observed, it may be possible to conclude that the direction of sediment transport is from d_1 to d_2 (Table A -1).

It is interesting to note that sediments cannot become coarser forever, because, with coarsening it becomes less and less likely that the transport processes will maintain high energy characteristics. As the deposits become coarser, the transfer function describing the processes will revert to a low energy function 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 A-1). Generally, however, the geological interpretation of the environments being sampled will clearly differentiate between the two Cases.

2.0 METHOD TO DETERMINE TRANSPORT DIRECTION FROM GRAIN-SIZE DISTRIBUTIONS

Clearly the model presented above does not result in perfect sequential changes of grain-size distributions in the direction of sediment transport, although numerous authors have recognized general changes in specific parameters (e.g. mean grain size or sorting). The model demands specific changes in all three parameters (mean, sorting

and skewness) to suggest a transport direction. Given such complicating factors as variability in 'original source', probable local and temporal variability in the transfer functions, and variable time intervals represented by the samples themselves, it is not surprising that sequential changes in grain-size distributions are seldom recognized.

One approach that appears to be successful in recognizing trends is a simple statistical method whereby the Case (Table A -1) is determined among all possible pairs in a sample 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 mean size, sorting and skewness, 8 possible trends exist; compared to d_1, d_2 may be: (i) finer (F), better sorted (B) and more negatively skewed (-); (ii) coarser (C), more poorly sorted (P) and more positively skewed (+); (iii) C, B, -; (iv) F, P, -; (v) C, P, -; (vi) F, B, +; (vii) C, B, +; or (viii) F, P +. Of these trends, only two are of interest, namely F, B, - (Case B) and C, B, + (Case A or C), for which there is a 1/8 probability of either occurring at random (p = 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 a preferred direction.

Using the Z-score in a one-tailed test, H is accepted if:

$$Z=\frac{x-Np}{\sqrt{Npq}} > 1.645 \text{(0.05 level of significance)}$$

or $$> 2.33 \text{ (0.01 level of significance)}$$

where: x = observed number of pairs representing a particular Case in one of the two opposing directions; N = total number of possible undirectional pairs.

$N = \frac{n^2-n}{2}$ where n = number of samples in sequence
$p = 0.125$; and
$q = 1.0 - p = 0.875$

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

$$\text{ie. } \frac{9^2 - 9}{2} = 36 \text{ (the total possible pairs in one direction)}$$

3.0 INTERPRETATION OF THE X-DISTRIBUTION

Empirical examination of X-distributions from a large number of different environments has shown that there are four basic shapes that the distributions can take relative to the distributions of D_1 and D_2 deposits (Fig. A -5). These are as follows:

(1) The shape of the X-distribution resembles the D_1 and D_2 distributions, and the modes of all three distributions are similar (Fig. A -5A). In this situation, the relative probability of grains being transported produces a similar distribution to the actual deposits. This suggests that the environment is in dynamic equilibrium and for every grain in the deposit, there is an equal probability that it will be transported and re-deposited (i.e. there is a grain by grain replacement along the transport path).

(2) The shapes of the three distributions are similar, but the mode of X is finer than the modes of D_1 and D_2 (Fig. A -5B). In this situation, more fine grains are being deposited than are being eroded and transported; thus the environment is undergoing net accretion.

(3) The shapes of the three distributions are similar, but the mode of X is coarser than the modes of D_1 and D_2 (Fig. A -5C). Thus, more grains are being eroded than being deposited and the environment is undergoing net erosion.

(4) Regardless of the shapes of D_1 and D_2, the X-distribution more or less increases monotonically over the complete size range of the deposits (Fig. A -5D). This occurs when sediment, once deposited, undergoes no further transport. The environment, therefore, is undergoing total deposition and further erosion and transport of sediment ceases.

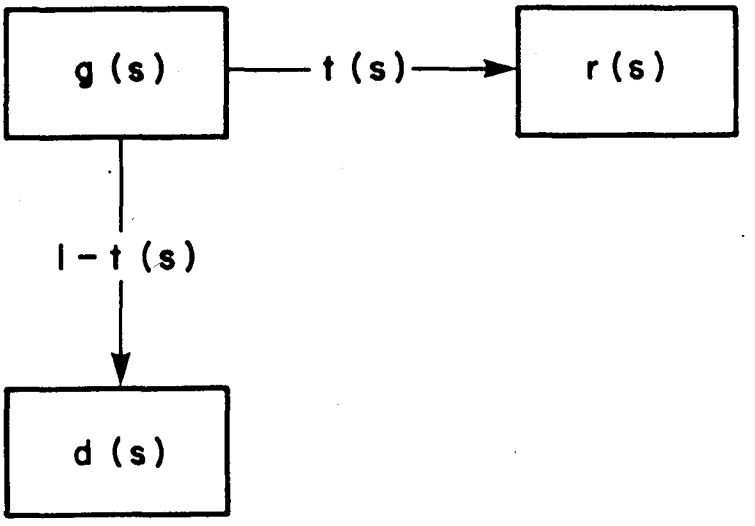


Figure A-1 : Sediment transport model to develop a lag deposit (see Appendix II for definition of terms).

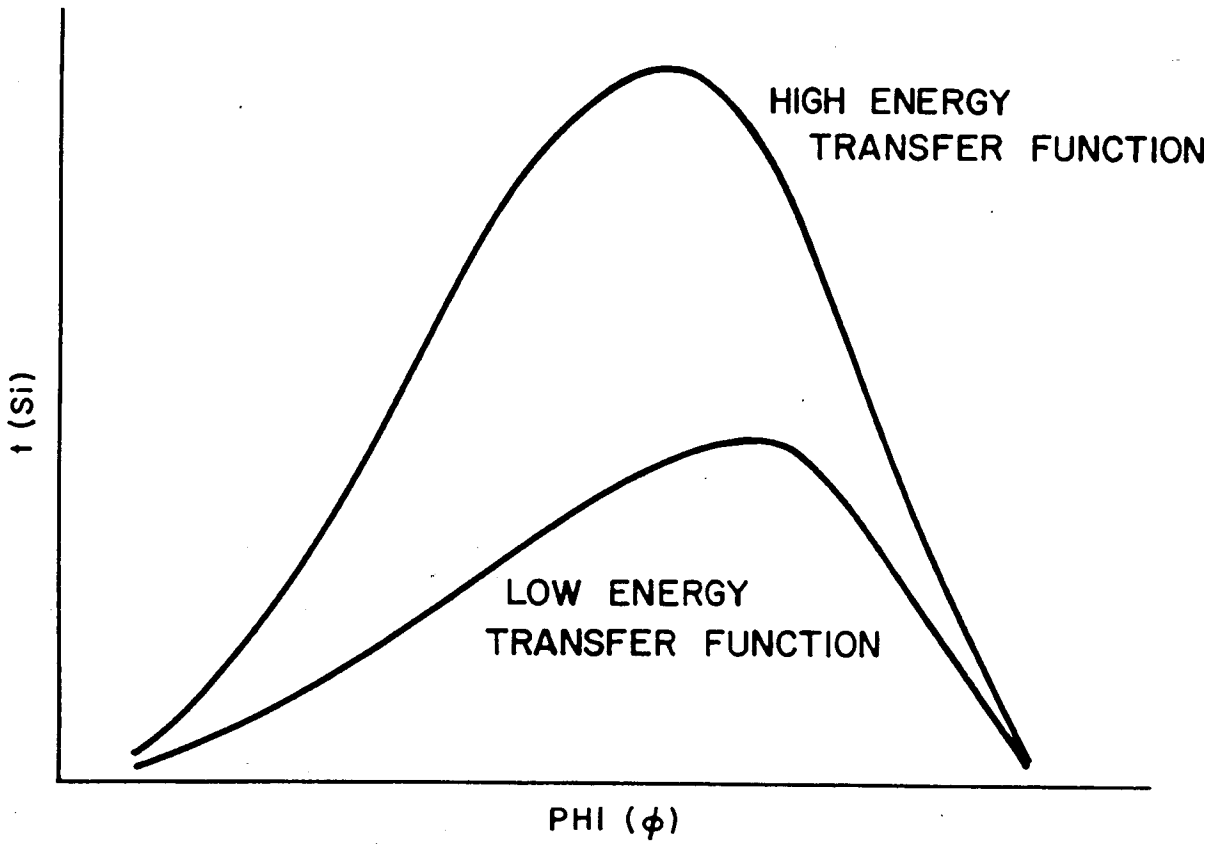


Figure A-2 : Diagram showing the extremes in shape of transfer functions (t(s)).

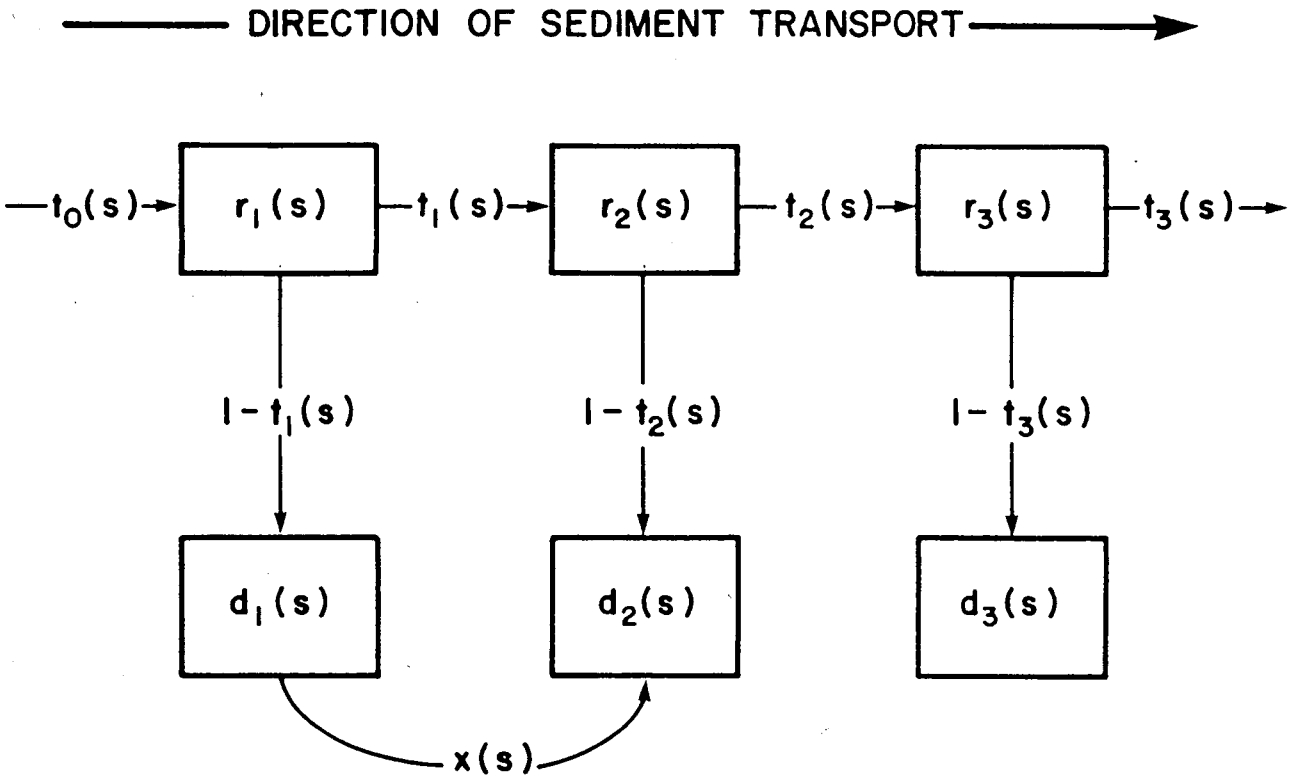
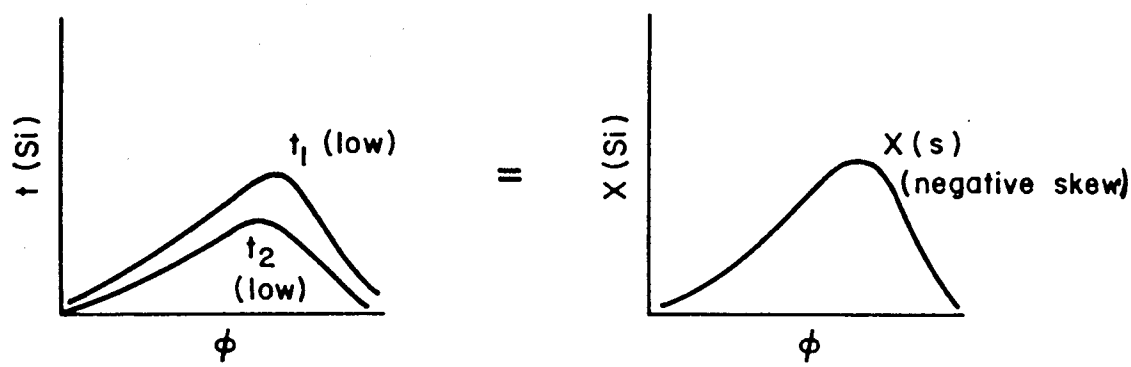


Figure A-3 : Sediment transport model relating deposits in the direction of transport (see Appendix I for definition of terms).

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

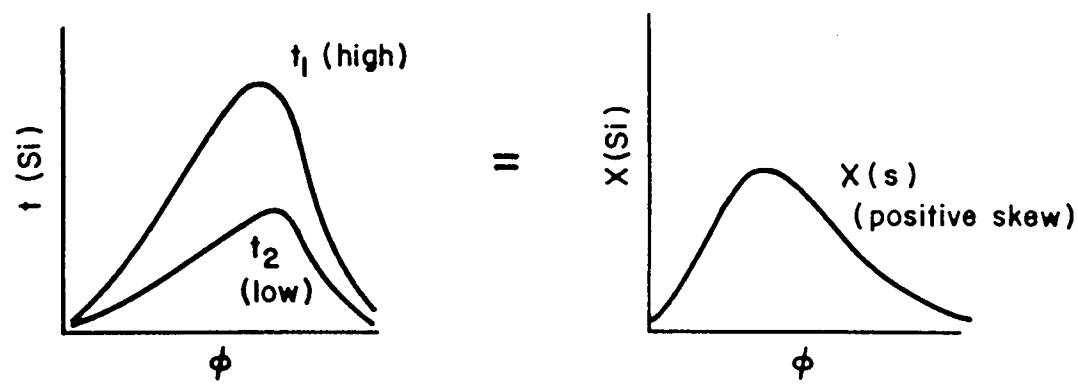


Figure A-4 : Summary diagram of t_1 and t_2 and corresponding X-distributions (equation 3) for Cases B and C (Table A-1).

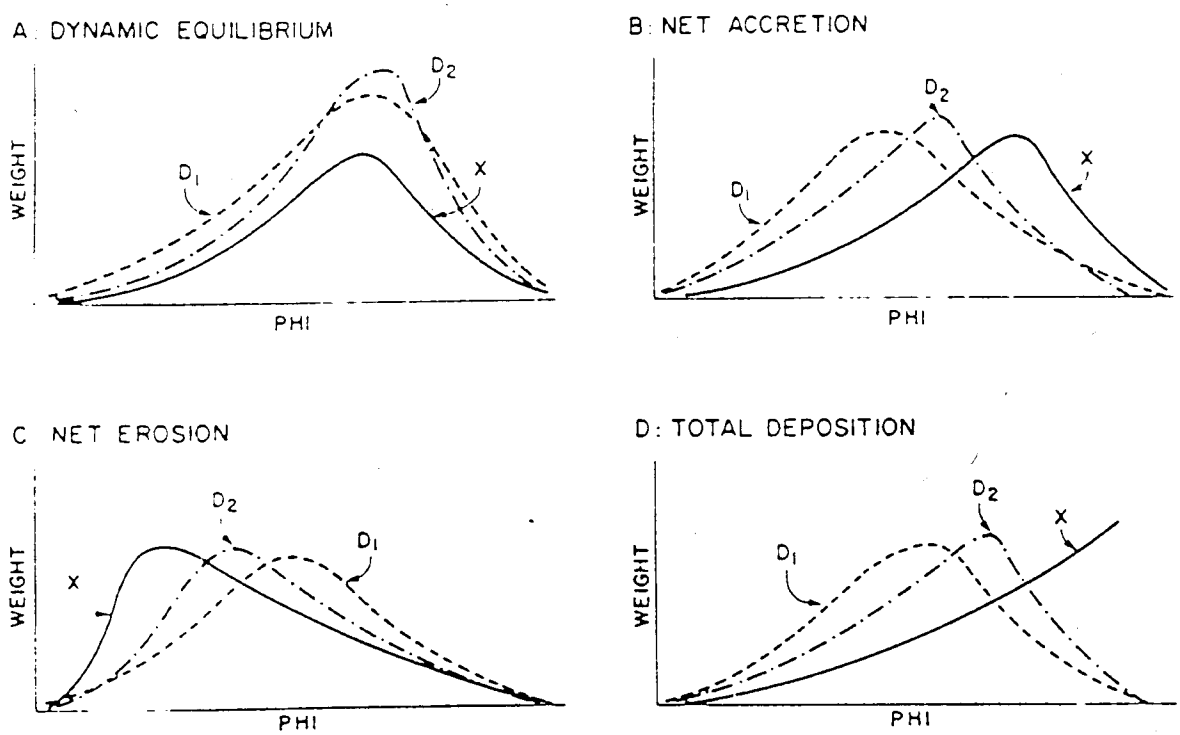


Figure A-5: Summary of the interpretations given to the shapes of X-distributions relative to the D_1 and D_2 deposits.

TABLE A-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 (Figure A-5)
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 (Figure A-5) (iv) t_2 is a high or low energy transfer function

APPENDIX IIA

Sediment trend statistics for all lines of sand samples (see Fig.3.)

Line statistics for sand samples

Definitions

1. **R^2** = multiple correlation coefficient derived from the mean, sorting and skewness of each sample distribution along the line. This is a relative indication of how well the samples are related by transport.

2. **Case B**: Sediments becoming finer, better sorted and more negatively skewed in the direction of transport.

3. **Case C**: Sediments becoming coarser, better sorted and more positively skewed in the direction of transport.

4. **N** = number of possible pairs in the line of samples.

5. **x** = number of pairs making a particular trend in a specific direction.

6. **Z** = Z-score statistic: ** are those samples significant at the 99% level. * are those trends significant at the 95% level.

7. Status (i.e. net erosion, accretion or dynamic equilibrium) is determined by the shape of the X-distribution.

8. Directions are always "Down" the line of samples. (On Figure 3, line numbers are placed at the "Down" end of each line).

TABLE IIA

Line	Case	R^2	Direction	N	x	Z	Status
1s	B	0.93	UP	15	0	-1.46	Accretion
			DOWN	15	11	7.12**	
	C		UP	15	3	0.88	
			DOWN	15	0	-1.46	
2s	B	0.94	UP	21	3	0.25	Accretion
			DOWN	21	11	5.53**	
	C		UP	21	5	1.57	
			DOWN	21	0	-1.73	
3s	B	0.95	UP	21	3	0.25	Accretion
			DOWN	21	7	2.89**	
	C		UP	21	4	0.91	
			DOWN	21	4	0.91	
4s	B	0.96	UP	21	3	0.25	Accretion
			DOWN	21	8	3.55**	
	C		UP	21	3	0.25	
			DOWN	21	4	0.91	
5s	B	0.91	UP	21	2	-0.41	Erosion
			DOWN	21	3	0.25	
	C		UP	21	3	0.25	
			DOWN	21	12	6.19**	
6s	B	0.73	UP	36	4	-0.25	Accretion
			DOWN	36	24	9.83**	
	C		UP	36	6	0.76	
			DOWN	36	1	-1.76	
7s	B	0.71	UP	36	2	-1.26	Accretion
			DOWN	36	22	8.82**	
	C		UP	36	6	0.76	
			DOWN	36	0	-2.27	
8s	B	0.78	UP	10	0	-1.20	Accretion
			DOWN	10	8	6.45**	
	C		UP	10	0	-1.20	
			DOWN	10	0	-1.20	
9s	B	0.75	UP	45	4	-0.73	Erosion
			DOWN	45	10	1.97*	
	C		UP	45	1	-2.08	
			DOWN	45	22	7.38**	

Line	Case	R^2	Direction	N	x	Z	Status
10s	B	0.69	UP	91	17	1.78*	Mixed Case
			DOWN	91	27	4.95**	
	C		UP	91	6	-1.70	
			DOWN	91	25	4.32**	
11s	B	0.86	UP	105	9	-1.22	Erosion
			DOWN	105	14	0.26	
	C		UP	105	8	-1.51	
			DOWN	105	57	12.95**	
12s	B	0.83	UP	91	10	-0.44	Mixed Case
			DOWN	91	31	6.22**	
	C		UP	91	15	1.15	
			DOWN	91	30	5.90**	
13s	B	0.86	UP	36	4	-0.25	Erosion
			DOWN	36	4	-0.25	
	C		UP	36	3	-0.76	
			DOWN	36	23	9.32**	
14s	B	0.85	UP	15	1	-0.68	Erosion
			DOWN	15	0	-1.46	
	C		UP	15	2	0.10	
			DOWN	15	11	7.12**	
15s	B	0.91	UP	21	1	-1.07	Erosion
			DOWN	21	0	-1.73	
	C		UP	21	3	0.25	
			DOWN	21	17	9.49**	
16s	B	0.75	UP	91	8	-1.07	Mixed Case
			DOWN	91	21	3.05**	
	C		UP	91	13	0.52	
			DOWN	91	43	10.02**	
17s	B	0.80	UP	105	7	-1.81	Erosion
			DOWN	105	20	2.03*	
	C		UP	105	17	1.14	
			DOWN	105	41	8.23**	
18s	B	0.77	DOWN	36	3	-0.76	Erosion
			UP	36	5	0.25	
	C		DOWN	36	13	4.28**	
			UP	36	2	-1.26	

TABLE IIA

Line	Case	R^2	Direction	N	x	Z	Status
19s	B	0.94	UP	36	5	0.25	Erosion
			DOWN	36	2	-1.26	
	C		UP	36	4	-0.25	
			DOWN	36	10	2.77**	
20s	B	0.95	UP	21	1	-1.07	Accretion
			DOWN	21	16	8.83**	
	C		UP	21	2	-0.41	
			DOWN	21	1	-1.07	
21s	B	0.84	UP	45	1	-2.08	Accretion
			DOWN	45	21	6.93**	
	C		UP	45	7	0.62	
			DOWN	45	2	-1.63	
22s	B	0.89	UP	45	2	-1.63	Accretion
			DOWN	45	22	7.38**	
	C		UP	45	5	-0.28	
			DOWN	45	3	-1.18	
23s	B	0.90	UP	36	6	0.76	Accretion
			DOWN	36	22	8.82**	
	C		UP	36	4	-0.25	
			DOWN	36	3	-0.76	
24s	B	0.61	UP	78	9	-0.26	Accretion
			DOWN	78	32	7.62**	
	C		UP	78	6	-1.28	
			DOWN	78	16	2.14*	
25s	B	0.65	UP	91	11	-0.12	Accretion
			DOWN	91	36	7.81**	
	C		UP	91	13	0.52	
			DOWN	91	13	0.52	
26s	B	0.82	UP	231	31	0.42	Accretion
			DOWN	231	110	16.14**	
	C		UP	231	19	-1.96	
			DOWN	231	35	1.22	
27s	B	0.69	UP	325	22	-3.12	Accretion
			DOWN	325	144	17.34**	
	C		UP	325	36	-0.78	
			DOWN	325	36	-0.78	

TABLE IIA

Line	Case	R^2	Direction	N	x	Z	Status
28s	B	0.59	UP	300	45	1.31	Accretion
			DOWN	300	137	17.37**	
	C		UP	300	20	-3.06	
			DOWN	300	37	-0.09	
29s	B	0.61	UP	253	32	0.07	Accretion
			DOWN	253	107	14.33**	
	C		UP	253	30	-0.31	
			DOWN	253	34	0.45	
30s	B	0.72	UP	253	38	1.21	Accretion
			DOWN	253	114	15.66**	
	C		UP	253	37	1.02	
			DOWN	253	15	-3.16	
31s	B	0.57	UP	378	28	-2.99	Accretion
			DOWN	378	197	23.29**	
	C		UP	378	38	-1.44	
			DOWN	378	31	-2.53	
32s	B	0.62	UP	190	30	1.37	Accretion
			DOWN	190	79	12.12**	
	C		UP	190	13	-2.36	
			DOWN	190	34	2.25*	
33s	B	0.70	UP	190	30	1.37	Mixed Case
			DOWN	190	78	11.90**	
	C		UP	190	13	-2.36	
			DOWN	190	35	2.47**	
34s	B	0.57	UP	231	38	1.82*	Mixed Case
			DOWN	231	81	10.37**	
	C		UP	231	14	-2.96	
			DOWN	231	48	3.80**	
35s	B	0.65	UP	36	6	0.76	Accretion
			DOWN	36	14	4.79**	
	C		UP	36	4	-0.25	
			DOWN	36	2	-1.26	
36s	B	0.09	UP	153	25	1.44	Accretion
			DOWN	153	45	6.33**	
	C		UP	153	21	0.46	
			DOWN	153	3	-3.94	

TABLE IIA

Line	Case	R^2	Direction	N	x	Z	Status
37s	B	0.53	UP	231	31	0.42	Accretion
			DOWN	231	88	11.76**	
	C		UP	231	36	1.42	
			DOWN	231	5	-4.75	
38s	B	0.98	UP	15	4	1.66*	Erosion
			DOWN	15	1	-0.68	
	C		UP	15	3	0.88	
			DOWN	15	5	2.44**	
39s	B	0.29	UP	78	7	-0.94	Accretion
			DOWN	78	23	4.54**	
	C		UP	78	11	0.43	
			DOWN	78	10	0.09	
40s	B	0.37	UP	66	7	-0.47	Accretion
			DOWN	66	22	5.12**	
	C		UP	66	7	-0.47	
			DOWN	66	8	-0.09	
41s	B	0.87	UP	28	5	0.86	Accretion
			DOWN	28	11	4.29**	
	C		UP	28	4	0.29	
			DOWN	28	0	-2.00	
42s	B	0.25	UP	28	2	-0.86	Accretion
			DOWN	28	9	3.14**	
	C		UP	28	3	-0.29	
			DOWN	28	1	-1.43	
43s	B	0.85	UP	66	1	-2.70	Mixed Case
			DOWN	66	19	4.00**	
	C		UP	66	5	-1.21	
			DOWN	66	32	8.84**	
44s	B	0.93	UP	120	15	0.00	Erosion
			DOWN	120	15	0.00	
	C		UP	120	14	-0.28	
			DOWN	120	63	13.25**	
45s	B	0.87	UP	91	13	0.52	Erosion
			DOWN	91	12	0.20	
	C		UP	91	18	2.10*	
			DOWN	91	38	8.44**	

Line	Case	R^2	Direction	N	x	Z	Status
46s	B	0.83	UP	55	8	0.46	Erosion
			DOWN	55	7	0.05	
	C		UP	55	12	2.09*	
			DOWN	55	18	4.54**	
47s	B	0.76	UP	21	2	-0.41	Accretion
			DOWN	21	10	4.87**	
	C		UP	21	4	0.91	
			DOWN	21	2	-0.41	
48s	B	0.60	UP	276	47	2.28*	Accretion
			DOWN	276	94	10.83**	
	C		UP	276	17	-3.19	
			DOWN	276	28	-1.18	
49s	B	0.00	UP	276	41	1.18	Accretion
			DOWN	276	80	8.28**	
	C		UP	276	17	-3.19	
			DOWN	276	19	-2.82	
50s	B	0.03	UP	210	19	-1.51	Accretion
			DOWN	210	54	5.79**	
	C		UP	210	8	-3.81	
			DOWN	210	12	-2.97	
51s	B	0.01	UP	231	18	-2.16	Accretion
			DOWN	231	66	7.39**	
	C		UP	231	10	-3.76	
			DOWN	231	22	-1.37	
52s	B	0.44	UP	45	0	-2.54	Accretion
			DOWN	45	19	6.03**	
	C		UP	45	4	-0.73	
			DOWN	45	3	-1.18	
53s	B	0.86	UP	45	1	-2.08	Accretion
			DOWN	45	19	6.03**	
	C		UP	45	4	-0.73	
			DOWN	45	1	-2.08	
54s	B	0.46	UP	45	2	-1.63	Accretion
			DOWN	45	13	3.32**	
	C		UP	45	2	-1.63	
			DOWN	45	0	-2.54	

TABLE IIA

Line	Case R^2	Direction	N	x	Z	Status
55s	B 0.57	UP	435	63	1.25	Accretion
		DOWN	435	122	9.80**	
	C	UP	435	33	-3.10	
		DOWN	435	46	-1.21	
56s	B 0.78	UP	351	56	1.96*	Accretion
		DOWN	351	155	17.93**	
	C	UP	351	25	-3.05	
		DOWN	351	50	0.99	
57s	B 0.73	UP	276	47	2.28*	Accretion
		DOWN	276	130	17.38**	
	C	UP	276	32	-0.46	
		DOWN	276	20	-2.64	
58s	B 0.39	UP	105	15	0.55	Accretion
		DOWN	105	54	12.06**	
	C	UP	105	4	-2.69	
		DOWN	105	3	-2.99	
59s	B 0.74	UP	78	12	0.77	Accretion
		DOWN	78	45	12.07**	
	C	UP	78	6	-1.28	
		DOWN	78	1	-3.00	
60s	B 0.69	UP	15	3	0.88	Erosion
		DOWN	15	0	-1.46	
	C	UP	15	0	-1.46	
		DOWN	15	8	4.78**	
61s	B 0.61	UP	45	5	-0.28	Erosion
		DOWN	45	6	0.17	
	C	UP	45	4	-0.73	
		DOWN	45	15	4.23**	
62s	B 0.36	UP	36	0	-2.27	Accretion
		DOWN	36	16	5.80**	
	C	UP	36	7	1.26	
		DOWN	36	1	-1.76	
63s	B 0.25	UP	78	14	1.46	Erosion
		DOWN	78	7	-0.94	
	C	UP	78	9	-0.26	
		DOWN	78	23	4.54**	

TABLE IIA

Line	Case R^2	Direction	N	x	Z	Status
64s	B 0.64	UP	78	9	-0.26	Accretion
		DOWN	78	36	8.99**	
	C	UP	78	10	0.09	
		DOWN	78	5	-1.63	
65s	B 0.42	UP	91	9	-0.75	Accretion
		DOWN	91	42	9.71**	
	C	UP	91	16	1.47	
		DOWN	91	4	-2.34	
66s	B 0.62	UP	66	3	-1.95	Erosion
		DOWN	66	11	1.02	
	C	UP	66	9	0.28	
		DOWN	66	19	4.00**	
67s	B 0.86	UP	120	9	-1.66	Erosion
		DOWN	120	14	-0.28	
	C	UP	120	16	0.28	
		DOWN	120	49	9.38**	
68s	B 0.77	UP	136	22	1.30	Erosion
		DOWN	136	24	1.81*	
	C	UP	136	7	-2.59	
		DOWN	136	56	10.11**	
69s	B 0.92	UP	66	6	-0.84	Erosion
		DOWN	66	8	-0.09	
	C	UP	66	9	0.28	
		DOWN	66	41	12.19**	
70s	B 0.99	UP	45	0	-2.54	Erosion
		DOWN	45	4	-0.73	
	C	UP	45	5	-0.28	
		DOWN	45	33	12.34**	
71s	B 0.95	UP	28	0	-2.00	Mixed Case
		DOWN	28	12	4.86**	
	C	UP	28	1	-1.43	
		DOWN	28	12	4.86**	
72s	B 0.80	UP	78	15	1.80*	Erosion
		DOWN	78	5	-1.63	
	C	UP	78	5	-1.63	
		DOWN	78	38	9.67**	

TABLE IIA

Line	Case	R^2	Direction	N	x	Z	Status
73s	B	0.87	UP	45	5	-0.28	Erosion
			DOWN	45	6	0.17	
	C		UP	45	6	0.17	
			DOWN	45	16	4.68**	
74s	B	0.74	UP	78	11	0.43	Erosion
			DOWN	78	11	0.43	
	C		UP	78	14	1.46	
			DOWN	78	27	5.91**	
75s	B	0.73	UP	153	25	1.44	Mixed Case
			DOWN	153	35	3.88**	
	C		UP	153	21	0.46	
			DOWN	153	33	3.39**	
76s	B	0.95	UP	45	10	1.97*	Erosion
			DOWN	45	5	-0.28	
	C		UP	45	9	1.52	
			DOWN	45	18	5.58**	
77s	B	0.99	UP	10	0	-1.20	Erosion
			DOWN	10	0	-1.20	
	C		UP	10	3	1.67*	
			DOWN	10	7	5.50**	
78s	B	1.00	UP	6	0	-0.93	Erosion
			DOWN	6	0	-0.93	
	C		UP	6	2	1.54	
			DOWN	6	4	4.01**	
79s	B	0.96	UP	10	2	0.72	Accretion
			DOWN	10	4	2.63**	
	C		UP	10	0	-1.20	
			DOWN	10	3	1.67*	
80s	B	0.98	UP	15	2	0.10	Erosion
			DOWN	15	3	0.88	
	C		UP	15	0	-1.46	
			DOWN	15	9	5.56**	
81s	B	0.98	UP	36	4	-0.25	Erosion
			DOWN	36	5	0.25	
	C		UP	36	4	-0.25	
			DOWN	36	22	8.82**	

Line	Case	R^2	Direction	N	x	Z	Status
82s	B	0.99	UP	45	4	-0.73	Mixed Case
			DOWN	45	17	5.13**	
	C		UP	45	2	-1.63	
			DOWN	45	20	6.48**	
83s	B	0.88	UP	21	4	0.91	Accretion
			DOWN	21	9	4.21**	
	C		UP	21	2	-0.41	
			DOWN	21	5	1.57	
84s	B	0.93	UP	28	6	1.43	Accretion
			DOWN	28	12	4.86**	
	C		UP	28	1	-1.43	
			DOWN	28	7	2.00*	
85s	B	0.97	UP	36	8	1.76*	Mixed Case
			DOWN	36	12	3.78**	
	C		UP	36	3	-0.76	
			DOWN	36	11	3.28**	
86s	B	0.97	UP	36	6	0.76	Accretion
			DOWN	36	16	5.80**	
	C		UP	36	4	-0.25	
			DOWN	36	8	1.76*	
87s	B	0.93	UP	66	13	1.77*	Mixed Case
			DOWN	66	20	4.37**	
	C		UP	66	7	-0.47	
			DOWN	66	19	4.00**	
88s	B	0.95	UP	91	13	0.52	Mixed Case
			DOWN	91	28	5.27**	
	C		UP	91	7	-1.39	
			DOWN	91	38	8.44**	
89s	B	0.93	UP	91	10	-0.44	Mixed Case
			DOWN	91	23	3.68**	
	C		UP	91	9	-0.75	
			DOWN	91	41	9.39**	
90s	B	0.92	UP	105	10	-0.92	Mixed Case
			DOWN	105	24	3.21**	
	C		UP	105	14	0.26	
			DOWN	105	50	10.88**	

TABLE IIA

Line	Case	R^2	Direction	N	x	Z	Status
91s	B	0.89	UP	136	13	-1.04	Erosion
			DOWN	136	24	1.81*	
	C		UP	136	11	-1.56	
			DOWN	136	68	13.22**	
92s	B	0.90	UP	153	18	-0.28	Mixed Case
			DOWN	153	29	2.41**	
	C		UP	153	6	-3.21	
			DOWN	153	84	15.86**	
93s	B	0.90	UP	153	12	-1.74	Erosion
			DOWN	153	26	1.68*	
	C		UP	153	22	0.70	
			DOWN	153	78	14.39**	
94s	B	0.88	UP	276	19	-2.82	Erosion
			DOWN	276	41	1.18	
	C		UP	276	39	0.82	
			DOWN	276	148	20.66**	
95s	B	0.86	UP	253	24	-1.45	Erosion
			DOWN	253	33	0.26	
	C		UP	253	35	0.64	
			DOWN	253	135	19.65**	
96s	B	0.99	UP	21	4	0.91	Mixed Case
			DOWN	21	9	4.21**	
	C		UP	21	1	-1.07	
			DOWN	21	7	2.89**	
97s	B	0.98	UP	10	1	-0.24	Accretion
			DOWN	10	4	2.63**	
	C		UP	10	2	0.72	
			DOWN	10	2	0.72	
98s	B	0.98	UP	15	1	-0.68	Erosion
			DOWN	15	2	0.10	
	C		UP	15	1	-0.68	
			DOWN	15	10	6.34**	
99s	B	0.96	UP	15	0	-1.46	Mixed Case
			DOWN	15	8	4.78**	
	C		UP	15	2	0.10	
			DOWN	15	5	2.44**	

TABLE IIA

Line	Case	R^2	Direction	N	x	Z	Status
100s	B	0.98	UP	28	6	1.43	Erosion
			DOWN	28	3	-0.29	
	C		UP	28	6	1.43	
			DOWN	28	8	2.57**	
101s	B	0.96	UP	28	4	0.29	Mixed Case
			DOWN	28	12	4.86**	
	C		UP	28	4	0.29	
			DOWN	28	8	2.57**	
102s	B	0.93	UP	28	6	1.43	Accretion
			DOWN	28	9	3.14**	
	C		UP	28	6	1.43	
			DOWN	28	5	0.86	
103s	B	0.95	UP	36	9	2.27*	Accretion
			DOWN	36	13	4.28**	
	C		UP	36	6	0.76	
			DOWN	36	6	0.76	
104s	B	0.84	UP	15	0	-1.46	Erosion
			DOWN	15	3	0.88	
	C		UP	15	4	1.66*	
			DOWN	15	6	3.22**	
105s	B	0.86	UP	15	0	-1.46	Mixed Case
			DOWN	15	5	2.44**	
	C		UP	15	3	0.88	
			DOWN	15	5	2.44**	
106s	B	0.70	UP	15	0	-1.46	Accretion
			DOWN	15	5	2.44**	
	C		UP	15	2	0.10	
			DOWN	15	2	0.10	
107s	B	0.72	UP	36	4	-0.25	Erosion
			DOWN	36	8	1.76*	
	C		UP	36	6	0.76	
			DOWN	36	12	3.78**	
108s	B	0.98	UP	28	6	1.43	Mixed Case
			DOWN	28	9	3.14**	
	C		UP	28	1	-1.43	
			DOWN	28	10	3.71**	

TABLE IIA

Line	Case	R^2	Direction	N	x	Z	Status
109s	B	0.92	UP	28	6	1.43	Erosion
			DOWN	28	7	2.00*	
	C		UP	28	1	-1.43	
			DOWN	28	12	4.86**	
110s	B	0.94	UP	21	6	2.23*	Erosion
			DOWN	21	4	0.91	
	C		UP	21	1	-1.07	
			DOWN	21	7	2.89**	
111s	B	0.46	UP	78	15	1.80*	Accretion
			DOWN	78	27	5.91**	
	C		UP	78	3	-2.31	
			DOWN	78	7	-0.94	
112s	B	0.69	UP	66	13	1.77*	Accretion
			DOWN	66	27	6.98**	
	C		UP	66	11	1.02	
			DOWN	66	4	-1.58	
113s	B	0.94	UP	45	10	1.97*	Accretion
			DOWN	45	17	5.13**	
	C		UP	45	4	-0.73	
			DOWN	45	10	1.97*	
114s	B	0.96	UP	28	7	2.00*	Erosion
			DOWN	28	4	0.29	
	C		UP	28	7	2.00*	
			DOWN	28	8	2.57**	
115s	B	0.96	UP	21	4	0.91	Erosion
			DOWN	21	3	0.25	
	C		UP	21	5	1.57	
			DOWN	21	9	4.21**	
116s	B	0.71	UP	28	6	1.43	Accretion
			DOWN	28	8	2.57**	
	C		UP	28	4	0.29	
			DOWN	28	5	0.86	
117s	B	0.73	UP	15	2	0.10	Mixed Case
			DOWN	15	5	2.44**	
	C		UP	15	1	-0.68	
			DOWN	15	5	2.44**	

Line	Case	R^2	Direction	N	x	Z	Status
118s	B	0.69	UP	15	3	0.88	Erosion
			DOWN	15	3	0.88	
	C		UP	15	0	-1.46	
			DOWN	15	5	2.44**	
119s	B	0.74	UP	10	3	1.67*	Accretion
			DOWN	10	4	2.63**	
	C		UP	10	0	-1.20	
			DOWN	10	2	0.72	
120s	B	0.76	UP	10	2	0.72	Accretion
			DOWN	10	4	2.63**	
	C		UP	10	1	-0.24	
			DOWN	10	2	0.72	
121s	B	0.84	UP	10	2	0.72	Erosion
			DOWN	10	0	-1.20	
	C		UP	10	0	-1.20	
			DOWN	10	7	5.50**	
122s	B	0.76	UP	190	18	-1.26	Mixed Case
			DOWN	190	61	8.17**	
	C		UP	190	25	0.27	
			DOWN	190	43	4.22**	
123s	B	0.90	UP	190	26	0.49	Mixed Case
			DOWN	190	54	6.64**	
	C		UP	190	25	0.27	
			DOWN	190	54	6.64**	
124s	B	0.84	UP	231	27	-0.37	Accretion
			DOWN	231	79	9.97**	
	C		UP	231	39	2.01*	
			DOWN	231	40	2.21*	
125s	B	0.97	UP	253	38	1.21	Mixed Case
			DOWN	253	94	11.86**	
	C		UP	253	41	1.78*	
			DOWN	253	58	5.01**	
126s	B	0.76	UP	253	39	1.40	Mixed Case
			DOWN	253	73	7.87**	
	C		UP	253	37	1.02	
			DOWN	253	50	3.49**	

Line	Case	R^2	Direction	N	x	Z	Status
127s	B	0.74	UP	253	35	0.64	Mixed Case
			DOWN	253	73	7.87**	
	C		UP	253	39	1.40	
			DOWN	253	61	5.58**	
128s	B	0.71	UP	253	37	1.02	Mixed Case
			DOWN	253	64	6.15**	
	C		UP	253	40	1.59	
			DOWN	253	57	4.82**	
129s	B	0.73	UP	276	38	0.64	Mixed Case
			DOWN	276	84	9.01**	
	C		UP	276	41	1.18	
			DOWN	276	61	4.82**	
130s	B	0.77	UP	276	42	1.37	Mixed Case
			DOWN	276	87	9.56**	
	C		UP	276	38	0.64	
			DOWN	276	54	3.55**	
131s	B	0.95	UP	231	35	1.22	Mixed Case
			DOWN	231	79	9.97**	
	C		UP	231	31	0.42	
			DOWN	231	63	6.79**	
132s	B	0.96	UP	231	35	1.22	Mixed Case
			DOWN	231	85	11.17**	
	C		UP	231	24	-0.97	
			DOWN	231	64	6.99**	
133s	B	0.84	UP	210	31	0.99	Mixed Case
			DOWN	210	52	5.37**	
	C		UP	210	35	1.83*	
			DOWN	210	53	5.58**	
134s	B	0.92	UP	210	37	2.24*	Mixed Case
			DOWN	210	46	4.12**	
	C		UP	210	33	1.41	
			DOWN	210	62	7.46**	
135s	B	0.90	UP	231	21	-1.57	Mixed Case
			DOWN	231	88	11.76**	
	C		UP	231	32	0.62	
			DOWN	231	59	5.99**	

Line	Case	R^2	Direction	N	x	Z	Status
136s	B	0.85	UP	231	28	-0.17	Mixed Case
			DOWN	231	79	9.97**	
	C		UP	231	30	0.22	
			DOWN	231	55	5.20**	
137s	B	0.85	UP	15	1	-0.68	Accretion
			DOWN	15	8	4.78**	
	C		UP	15	0	-1.46	
			DOWN	15	4	1.66*	
138s	B	0.47	UP	91	10	-0.44	Erosion
			DOWN	91	9	-0.75	
	C		UP	91	17	1.78*	
			DOWN	91	22	3.37**	
139s	B	0.70	UP	91	13	0.52	Erosion
			DOWN	91	8	-1.07	
	C		UP	91	17	1.78*	
			DOWN	91	29	5.59**	
140s	B	0.83	UP	45	7	0.62	Erosion
			DOWN	45	6	0.17	
	C		UP	45	9	1.52	
			DOWN	45	17	5.13**	
141s	B	0.94	UP	21	0	-1.73	Mixed Case
			DOWN	21	8	3.55**	
	C		UP	21	3	0.25	
			DOWN	21	7	2.89**	
142s	B	0.78	UP	21	3	0.25	Accretion
			DOWN	21	7	2.89**	
	C		UP	21	2	-0.41	
			DOWN	21	4	0.91	
143s	B	0.80	UP	45	4	-0.73	Accretion
			DOWN	45	23	7.83**	
	C		UP	45	4	-0.73	
			DOWN	45	7	0.62	
144s	B	0.85	UP	45	9	1.52	Accretion
			DOWN	45	20	6.48**	
	C		UP	45	7	0.62	
			DOWN	45	6	0.17	

TABLE IIA

Line	Case	R^2	Direction	N	x	Z	Status
145s	B	0.99	UP	66	3	-1.95	Accretion
			DOWN	66	40	11.82**	
	C		UP	66	14	2.14*	
			DOWN	66	3	-1.95	
146s	B	0.93	UP	36	3	-0.76	Accreti
			DOWN	36	16	5.80**	
	C		UP	36	5	0.25	
			DOWN	36	7	1.26	
147s	B	0.97	UP	21	4	0.91	Accretion
			DOWN	21	12	6.19**	
	C		UP	21	1	-1.07	
			DOWN	21	1	-1.07	
148s	B	0.97	UP	21	4	0.91	Accretion
			DOWN	21	11	5.53**	
	C		UP	21	2	-0.41	
			DOWN	21	1	-1.07	
149s	B	0.75	UP	10	1	-0.24	Accretion
			DOWN	10	5	3.59**	
	C		UP	10	0	-1.20	
			DOWN	10	3	1.67*	
150s	B	0.96	UP	21	0	-1.73	Mixed Case
			DOWN	21	10	4.87**	
	C		UP	21	2	-0.41	
			DOWN	21	7	2.89**	
151s	B	0.95	UP	28	2	-0.86	Accretion
			DOWN	28	13	5.43**	
	C		UP	28	7	2.00*	
			DOWN	28	6	1.43	
152s	B	0.96	UP	36	2	-1.26	Accretion
			DOWN	36	17	6.30**	
	C		UP	36	8	1.76*	
			DOWN	36	6	0.76	
153s	B	0.98	UP	36	6	0.76	Accretion
			DOWN	36	15	5.29**	
	C		UP	36	7	1.26	
			DOWN	36	4	-0.25	

Line	Case	R^2	Direction	N	x	Z	Status
154s	B	0.98	UP	36	4	-0.25	Accretion
			DOWN	36	18	6.80**	
	C		UP	36	7	1.26	
			DOWN	36	4	-0.25	
155s	B	0.96	UP	36	5	0.25	Accretion
			DOWN	36	20	7.81**	
	C		UP	36	7	1.26	
			DOWN	36	2	-1.26	
156s	B	0.94	UP	36	2	-1.26	Accretion
			DOWN	36	19	7.31**	
	C		UP	36	6	0.76	
			DOWN	36	5	0.25	
157s	B	0.94	UP	36	5	0.25	Accretion
			DOWN	36	13	4.28**	
	C		UP	36	9	2.27*	
			DOWN	36	5	0.25	
158s	B	0.73	UP	28	3	-0.29	Accretion
			DOWN	28	9	3.14**	
	C		UP	28	6	1.43	
			DOWN	28	6	1.43	
159s	B	0.82	UP	36	6	0.76	Erosion
			DOWN	36	8	1.76*	
	C		UP	36	5	0.25	
			DOWN	36	10	2.77**	
160s	B	0.77	UP	55	11	1.68*	Accretion
			DOWN	55	13	2.50**	
	C		UP	55	12	2.09*	
			DOWN	55	11	1.68*	
161s	B	0.78	UP	55	8	0.46	Accretion
			DOWN	55	21	5.76**	
	C		UP	55	8	0.46	
			DOWN	55	10	1.27	
162s	B	0.68	UP	66	13	1.77*	Mixed Case
			DOWN	66	20	4.37**	
	C		UP	66	6	-0.84	
			DOWN	66	17	3.26**	

Line	Case	R^2	Direction	N	x	Z	Status
163s	B	0.76	UP	91	16	1.47	Accretion
			DOWN	91	35	7.49**	
	C		UP	91	10	-0.44	
			DOWN	91	12	0.20	
164s	B	0.86	UP	105	19	1.73*	Mixed Case
			DOWN	105	44	9.11**	
	C		UP	105	9	-1.22	
			DOWN	105	22	2.62**	
165s	B	0.85	UP	105	8	-1.51	Mixed Case
			DOWN	105	36	6.75**	
	C		UP	105	21	2.32*	
			DOWN	105	26	3.80**	
166s	B	0.75	UP	91	11	-0.12	Mixed Case
			DOWN	91	24	4.00**	
	C		UP	91	18	2.10*	
			DOWN	91	25	4.32**	
167s	B	0.89	UP	105	17	1.14	Mixed Case
			DOWN	105	28	4.39**	
	C		UP	105	10	-0.92	
			DOWN	105	41	8.23**	
168s	B	0.87	UP	91	9	-0.75	Mixed Case
			DOWN	91	29	5.59**	
	C		UP	91	15	1.15	
			DOWN	91	31	6.22**	
169s	B	0.91	UP	91	9	-0.75	Mixed Case
			DOWN	91	38	8.44**	
	C		UP	91	18	2.10*	
			DOWN	91	21	3.05**	
170s	B	0.99	UP	10	0	-1.20	Erosion
			DOWN	10	1	-0.24	
	C		UP	10	2	0.72	
			DOWN	10	7	5.50**	
171s	B	0.96	UP	15	4	1.66*	Erosion
			DOWN	15	0	-1.46	
	C		UP	15	1	-0.68	
			DOWN	15	10	6.34**	

Line	Case	R^2	Direction	N	x	Z	Status
172s	B	0.86	UP	28	7	2.00*	Erosion
			DOWN	28	0	-2.00	
	C		UP	28	4	0.29	
			DOWN	28	13	5.43**	
173s	B	0.78	UP	28	7	2.00*	Erosion
			DOWN	28	4	0.29	
	C		UP	28	2	-0.86	
			DOWN	28	9	3.14**	
174s	B	0.85	UP	28	5	0.86	Erosion
			DOWN	28	5	0.86	
	C		UP	28	4	0.29	
			DOWN	28	10	3.71**	
175s	B	0.63	UP	15	4	1.66*	Erosion
			DOWN	15	2	0.10	
	C		UP	15	0	-1.46	
			DOWN	15	5	2.44**	

APPENDIX IIB

Sediment trend statistics for all lines of mud samples (see Fig.5.)

Line statistics for mud samples

Definitions

1. **R^2** = multiple correlation coefficient derived from the mean, sorting and skewness of each sample distribution along the line. This is a relative indication of how well the samples are related by transport.

2. **Case B**: Sediments becoming finer, better sorted and more negatively skewed in the direction of transport.

3. **Case C**: Sediments becoming coarser, better sorted and more positively skewed in the direction of transport.

4. **N** = number of possible pairs in the line of samples.

5. **x** = number of pairs making a particular trend in a specific direction.

6. **Z** = Z-score statistic: ** are those samples significant at the 99% level. * are those trends significant at the 95% level.

7. Status (i.e. net erosion, accretion or dynamic equilibrium) is determined by the shape of the X-distribution.

8. Directions are always "Down" the line of samples. (On Figure 5, line numbers are placed at the "Down" end of each line).

TABLE IIB

Line	Case	R^2	Direction	N	x	Z	Status
1m	B	0.85	UP	10	2	0.72	Accretion
			DOWN	10	6	4.54**	
	C		UP	10	1	-0.24	
			DOWN	10	0	-1.20	
2m	B	0.91	UP	55	6	-0.36	Deposition
			DOWN	55	35	11.47**	
	C		UP	55	1	-2.40	
			DOWN	55	2	-1.99	
3m	B	0.85	UP	78	15	1.80*	Accretion
			DOWN	78	39	10.01**	
	C		UP	78	1	-3.00	
			DOWN	78	2	-2.65	
4m	B	0.77	UP	66	13	1.77*	Accretion
			DOWN	66	23	5.49**	
	C		UP	66	9	0.28	
			DOWN	66	3	-1.95	
5m	B	0.77	UP	6	1	0.31	Accretion
			DOWN	6	4	4.01**	
	C		UP	6	0	-0.93	
			DOWN	6	0	-0.93	
6m	B	0.93	UP	21	0	-1.73	Accretion
			DOWN	21	6	2.23*	
	C		UP	21	3	0.25	
			DOWN	21	7	2.89**	
7m	B	0.97	UP	28	7	2.00*	Accretion
			DOWN	28	12	4.86**	
	C		UP	28	4	0.29	
			DOWN	28	2	-0.86	
8m	B	0.82	UP	21	0	-1.73	Accretion
			DOWN	21	10	4.87**	
	C		UP	21	1	-1.07	
			DOWN	21	2	-0.41	
9m	B	0.83	UP	66	8	-0.09	Deposition
			DOWN	66	24	5.86**	
	C		UP	66	5	-1.21	
			DOWN	66	6	-0.84	

TABLE IIB

Line	Case	R^2	Direction	N	x	Z	Status
10m	B	0.80	UP	91	13	0.52	Deposition
			DOWN	91	37	8.12**	
	C		UP	91	3	-2.65	
			DOWN	91	5	-2.02	
11m	B	0.66	UP	55	6	-0.36	Accretion
			DOWN	55	29	9.02**	
	C		UP	55	4	-1.17	
			DOWN	55	3	-1.58	
12m	B	0.87	UP	66	7	-0.47	Accretion
			DOWN	66	39	11.44**	
	C		UP	66	4	-1.58	
			DOWN	66	4	-1.58	
13m	B	0.83	UP	78	11	0.43	Accretion
			DOWN	78	29	6.59**	
	C		UP	78	7	-0.94	
			DOWN	78	6	-1.28	
14m	B	0.90	UP	66	5	-1.21	Accretion
			DOWN	66	29	7.72**	
	C		UP	66	9	0.28	
			DOWN	66	7	-0.47	
15m	B	0.89	UP	190	25	0.27	Mixed Case
			DOWN	190	53	6.42**	
	C		UP	190	31	1.59	
			DOWN	190	35	2.47**	
16m	B	0.87	UP	120	23	2.21*	Accretion
			DOWN	120	40	6.90**	
	C		UP	120	22	1.93*	
			DOWN	120	11	-1.10	
17m	B	1.00	UP	15	2	0.10	Deposition
			DOWN	15	8	4.78**	
	C		UP	15	2	0.10	
			DOWN	15	0	-1.46	
18m	B	0.96	UP	10	2	0.72	Accretion
			DOWN	10	4	2.63**	
	C		UP	10	2	0.72	
			DOWN	10	1	-0.24	

Line	Case	R^2	Direction	N	x	Z	Status
19m	B	0.91	DOWN	45	22	7.38**	Deposition
			UP	45	5	-0.28	
	C		DOWN	45	4	-0.73	
			UP	45	9	1.52	
20m	B	0.96	UP	45	6	0.17	Deposition
			DOWN	45	27	9.63**	
	C		UP	45	7	0.62	
			DOWN	45	0	-2.54	
21m	B	0.93	UP	28	6	1.43	Equilibrium
			DOWN	28	5	0.86	
	C		UP	28	1	-1.43	
			DOWN	28	9	3.14**	
22m	B	0.87	UP	120	5	-2.76	Deposition
			DOWN	120	68	14.63**	
	C		UP	120	10	-1.38	
			DOWN	120	5	-2.76	
23m	B	0.98	UP	28	6	1.43	Accretion
			DOWN	28	10	3.71**	
	C		UP	28	4	0.29	
			DOWN	28	2	-0.86	
24m	B	0.86	UP	231	30	0.22	Accretion
			DOWN	231	95	13.16**	
	C		UP	231	16	-2.56	
			DOWN	231	27	-0.37	
25m	B	0.85	UP	300	48	1.83*	Accretion
			DOWN	300	103	11.43**	
	C		UP	300	22	-2.71	
			DOWN	300	32	-0.96	
26m	B	0.96	UP	15	0	-1.46	Accretion
			DOWN	15	13	8.69**	
	C		UP	15	2	0.10	
			DOWN	15	0	-1.46	
27m	B	0.85	UP	66	10	0.65	Accretion
			DOWN	66	15	2.51**	
	C		UP	66	11	1.02	
			DOWN	66	8	-0.09	

TABLE IIB

Line	Case	R^2	Direction	N	x	Z	Status
28m	B	0.69	UP	78	11	0.43	Accretion
			DOWN	78	17	2.48**	
	C		UP	78	9	-0.26	
			DOWN	78	1	-3.00	
29m	B	0.84	UP	190	31	1.59	Accretion
			DOWN	190	82	12.78**	
	C		UP	190	13	-2.36	
			DOWN	190	21	-0.60	
30m	B	0.81	UP	190	32	1.81*	Accretion
			DOWN	190	81	12.56**	
	C		UP	190	12	-2.58	
			DOWN	190	25	0.27	
31m	B	0.85	UP	171	29	1.76*	Accretion
			DOWN	171	62	9.39**	
	C		UP	171	18	-0.78	
			DOWN	171	20	-0.32	
32m	B	0.86	UP	153	26	1.68*	Accretion
			DOWN	153	56	9.01**	
	C		UP	153	14	-1.25	
			DOWN	153	20	0.21	
33m	B	0.87	UP	136	23	1.56	Accretion
			DOWN	136	46	7.52**	
	C		UP	136	14	-0.78	
			DOWN	136	16	-0.26	
34m	B	0.88	DOWN	153	55	8.77**	Accretion
			UP	153	14	-1.25	
	C		DOWN	153	20	0.21	
			UP	153	28	2.17*	
35m	B	0.83	UP	190	34	2.25*	Accretion
			DOWN	190	69	9.93**	
	C		UP	190	24	0.05	
			DOWN	190	20	-0.82	
36m	B	0.82	UP	231	38	1.82*	Accretion
			DOWN	231	93	12.76**	
	C		UP	231	25	-0.77	
			DOWN	231	21	-1.57	

TABLE IIB

Line	Case	R^2	Direction	N	x	Z	Status
37m	B	0.85	UP	120	23	2.21*	Accretion
			DOWN	120	36	5.80**	
	C		UP	120	14	-0.28	
			DOWN	120	12	-0.83	
38m	B	0.69	UP	45	4	-0.73	Deposition
			DOWN	45	15	4.23**	
	C		UP	45	7	0.62	
			DOWN	45	4	-0.73	
39m	B	0.99	UP	10	2	0.72	Accretion
			DOWN	10	5	3.59**	
	C		UP	10	2	0.72	
			DOWN	10	0	-1.20	
40m	B	0.74	UP	21	0	-1.73	Accretion
			DOWN	21	7	2.89**	
	C		UP	21	4	0.91	
			DOWN	21	0	-1.73	
41m	B	1.00	UP	3	1	1.09	Accretion
			DOWN	3	2	2.84**	
	C		UP	3	0	-0.65	
			DOWN	3	0	-0.65	
42m	B	1.00	UP	3	1	1.09	Accretion
			DOWN	3	2	2.84**	
	C		UP	3	0	-0.65	
			DOWN	3	0	-0.65	
43m	B	0.97	UP	15	3	0.88	Equilibrium
			DOWN	15	4	1.66*	
	C		UP	15	0	-1.46	
			DOWN	15	6	3.22**	
44m	B	0.99	UP	10	3	1.67*	Deposition
			DOWN	10	7	5.50**	
	C		UP	10	0	-1.20	
			DOWN	10	0	-1.20	
45m	B	0.87	UP	21	3	0.25	Accretion
			DOWN	21	9	4.21**	
	C		UP	21	3	0.25	
			DOWN	21	1	-1.07	

TABLE IIB

Line	Case	R^2	Direction	N	x	Z	Status
46m	B	0.86	UP	10	1	-0.24	Accretion
			DOWN	10	7	5.50**	
	C		UP	10	0	-1.20	
			DOWN	10	0	-1.20	
47m	B	0.81	UP	36	1	-1.76	Accretion
			DOWN	36	16	5.80**	
	C		UP	36	0	-2.27	
			DOWN	36	0	-2.27	
48m	B	0.96	UP	36	1	-1.76	Accretion
			DOWN	36	27	11.34**	
	C		UP	36	1	-1.76	
			DOWN	36	2	-1.26	
49m	B	0.94	UP	136	12	-1.30	Accretion
			DOWN	136	97	20.74**	
	C		UP	136	4	-3.37	
			DOWN	136	2	-3.89	
50m	B	0.92	UP	136	0	-4.41	Accretion
			DOWN	136	109	23.85**	
	C		UP	136	4	-3.37	
			DOWN	136	2	-3.89	
51m	B	1.00	UP	15	2	0.10	Accretion
			DOWN	15	8	4.78**	
	C		UP	15	1	-0.68	
			DOWN	15	1	-0.68	
52m	B	0.95	UP	15	3	0.88	Accretion
			DOWN	15	9	5.56**	
	C		UP	15	1	-0.68	
			DOWN	15	1	-0.68	
53m	B	0.90	UP	276	14	-3.73	Accretion
			DOWN	276	195	29.21**	
	C		UP	276	17	-3.19	
			DOWN	276	9	-4.64	
54m	B	0.73	UP	190	9	-3.24	Accretion
			DOWN	190	132	23.75**	
	C		UP	190	9	-3.24	
			DOWN	190	10	-3.02	

TABLE IIB

Line	Case	R^2	Direction	N	x	Z	Status
55m	B	0.95	UP	120	2	-3.59	Accretion
			DOWN	120	77	17.11**	
	C		UP	120	12	-0.83	
			DOWN	120	1	-3.86	
56m	B	1.00	UP	6	1	0.31	Accretion
			DOWN	6	4	4.01**	
	C		UP	6	0	-0.93	
			DOWN	6	0	-0.93	
57m	B	0.92	UP	36	2	-1.26	Accretion
			DOWN	36	25	10.33**	
	C		UP	36	5	0.25	
			DOWN	36	1	-1.76	
58m	B	0.91	UP	36	2	-1.26	Accretion
			DOWN	36	25	10.33**	
	C		UP	36	5	0.25	
			DOWN	36	1	-1.76	
59m	B	0.97	UP	21	5	1.57	Deposition
			DOWN	21	7	2.89**	
	C		UP	21	3	0.25	
			DOWN	21	3	0.25	
60m	B	0.93	UP	36	5	0.25	Deposition
			DOWN	36	15	5.29**	
	C		UP	36	3	-0.76	
			DOWN	36	3	-0.76	
61m	B	0.95	DOWN	36	15	5.29**	Accretion
			UP	36	3	-0.76	
	C		DOWN	36	2	-1.26	
			UP	36	6	0.76	
62m	B	0.97	UP	15	1	-0.68	Deposition
			DOWN	15	7	4.00**	
	C		UP	15	2	0.10	
			DOWN	15	1	-0.68	
63m	B	0.98	UP	10	2	0.72	Deposition
			DOWN	10	5	3.59**	
	C		UP	10	2	0.72	
			DOWN	10	0	-1.20	

TABLE IIB

Line	Case	R^2	Direction	N	x	Z	Status
64m	B	0.89	UP	15	3	0.88	Accretion
			DOWN	15	5	2.44**	
	C		UP	15	3	0.88	
			DOWN	15	0	-1.46	
65m	B	0.98	UP	28	4	0.29	Accretion
			DOWN	28	8	2.57**	
	C		UP	28	7	2.00*	
			DOWN	28	2	-0.86	
66m	B	0.81	UP	21	5	1.57	Accretion
			DOWN	21	9	4.21**	
	C		UP	21	2	-0.41	
			DOWN	21	0	-1.73	
67m	B	0.84	UP	10	0	-1.20	Equilibrium
			DOWN	10	4	2.63**	
	C		UP	10	1	-0.24	
			DOWN	10	1	-0.24	

APPENDIX III

Selected D1, D2 and X distributions for each of the transport environments defined in Figures 3 and 5

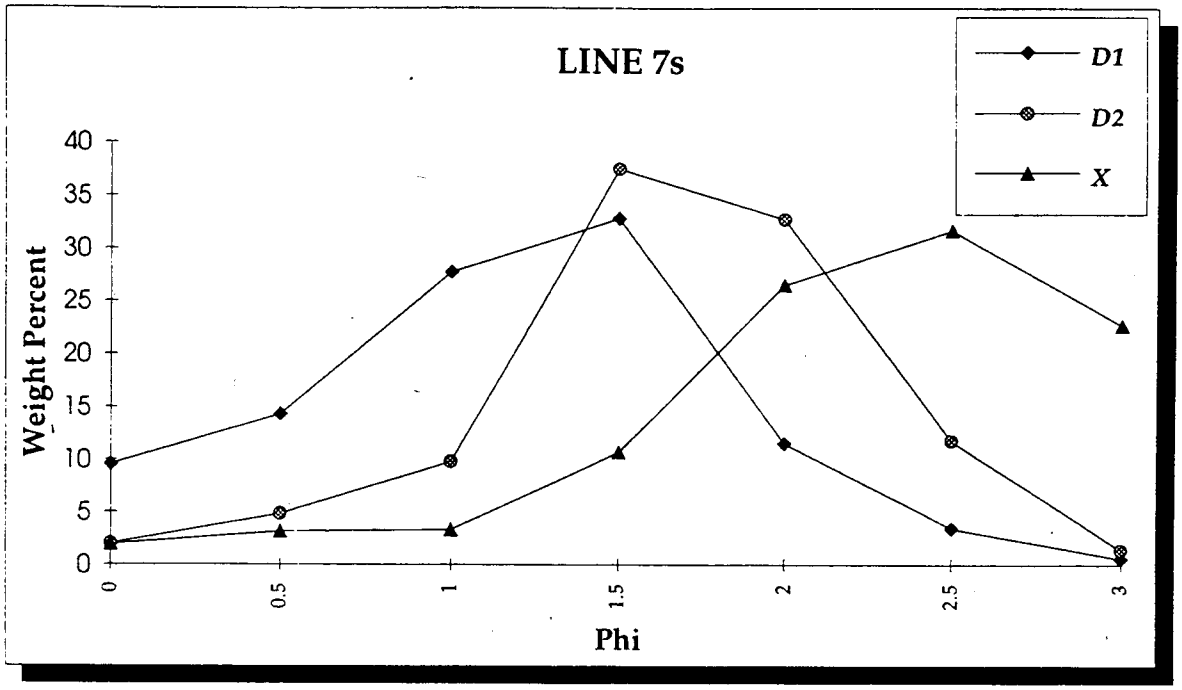


FIGURE A III - 1: D_1, D_2 and X for Line 7s showing net accretion in Environment 1 (Douglas Island).

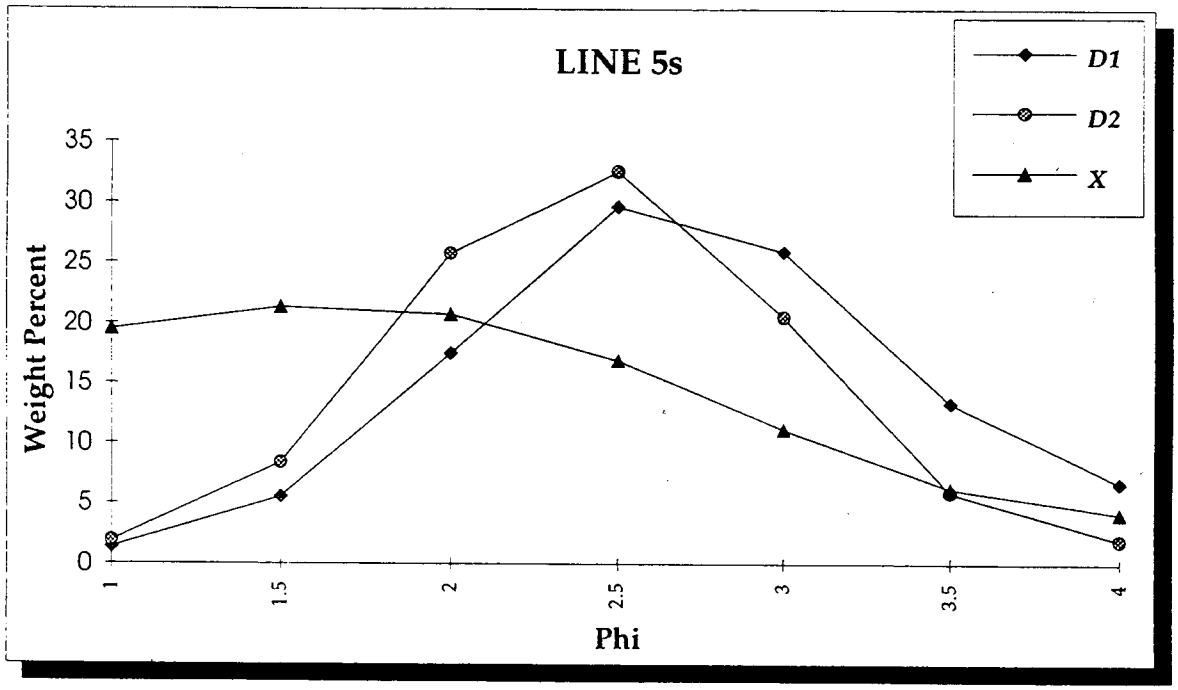


FIGURE A III - 2: D_1, D_2 and X for Line 5s. The X distribution indicates net erosion along the left bank of the Douglas Island transport environment.

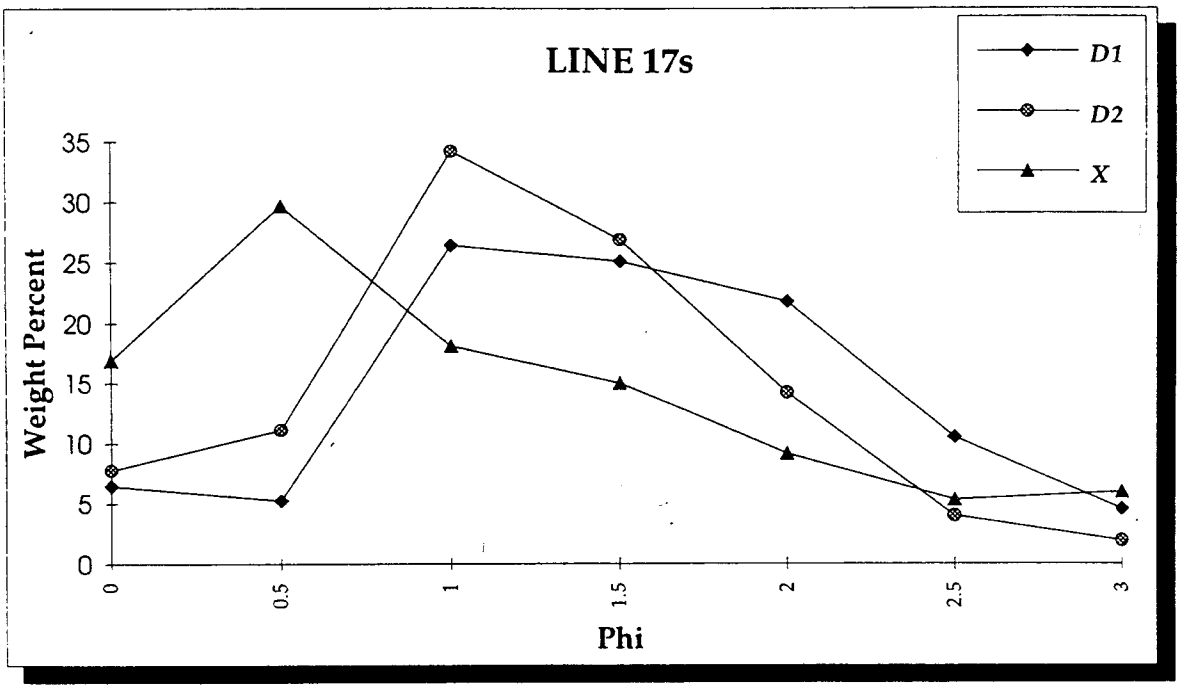


FIGURE A III - 3: D_1, D_2 and X for Line 17s (Coquitlam River/ Pitt River transport regime) showing an X-distribution indicative of net erosion.

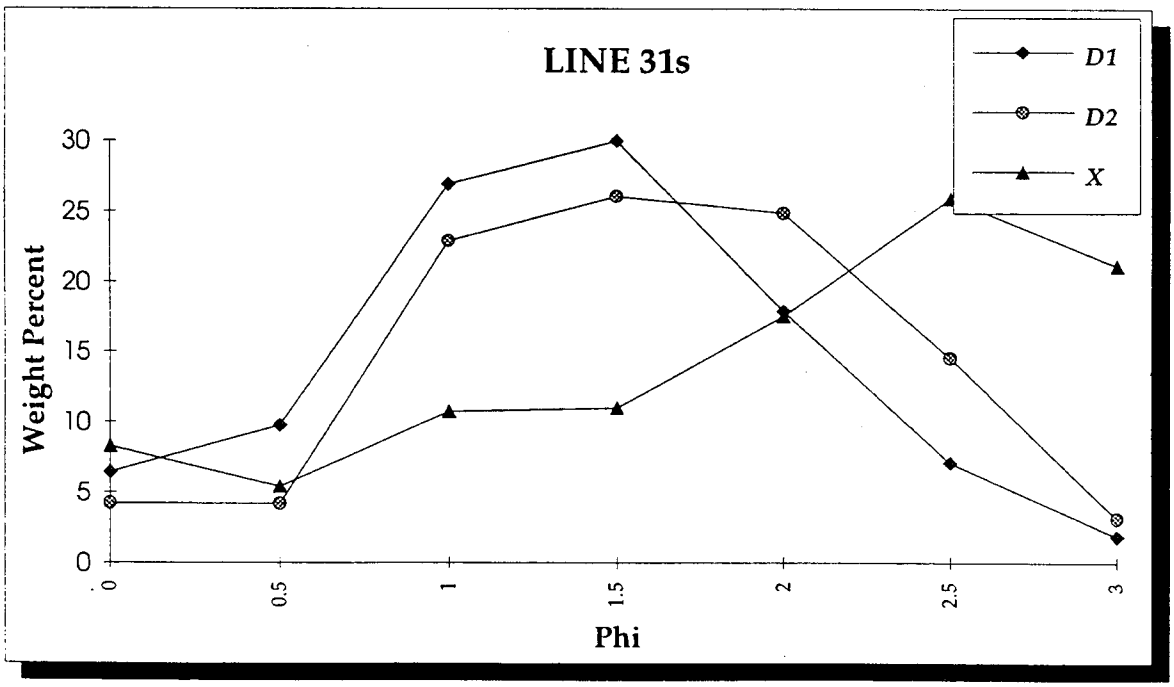


FIGURE A III - 4: D_1, D_2 and X for Line 31s (Environment 3; Queen's Reach/ Sapperton Channel). The X-distribution is indicative of net accretion.

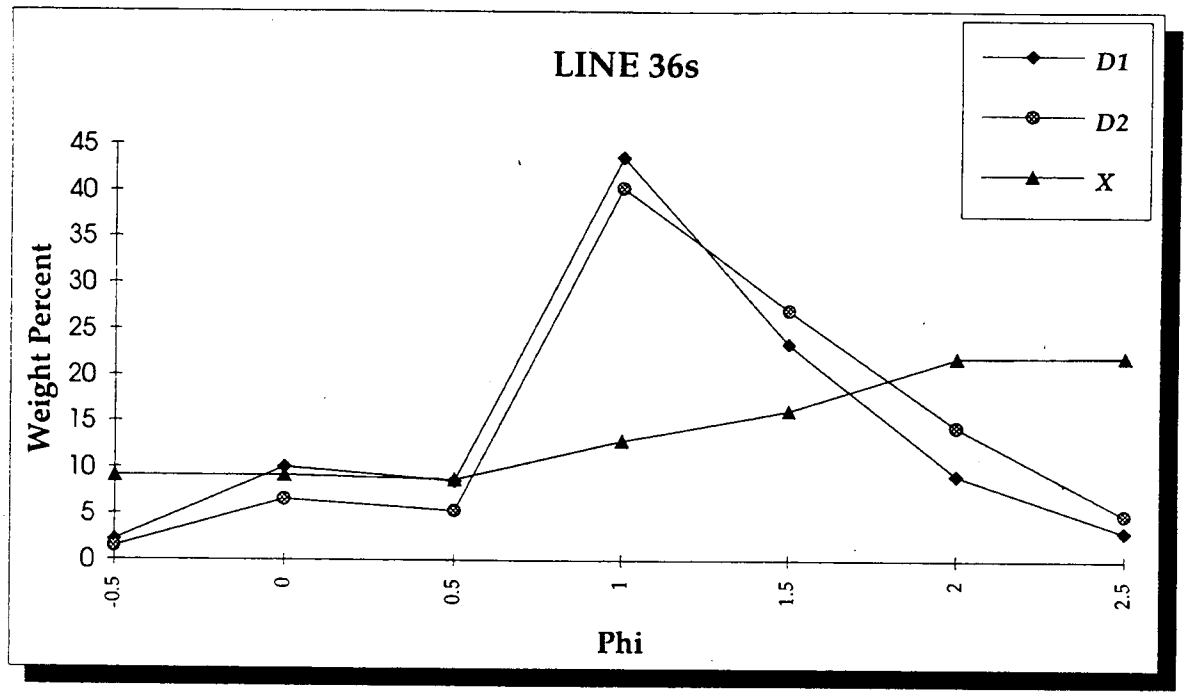


FIGURE A III - 5: D_1, D_2 and X for Line 36s (Environment 4; Eastern North Arm) showing net accretion along the transport path.

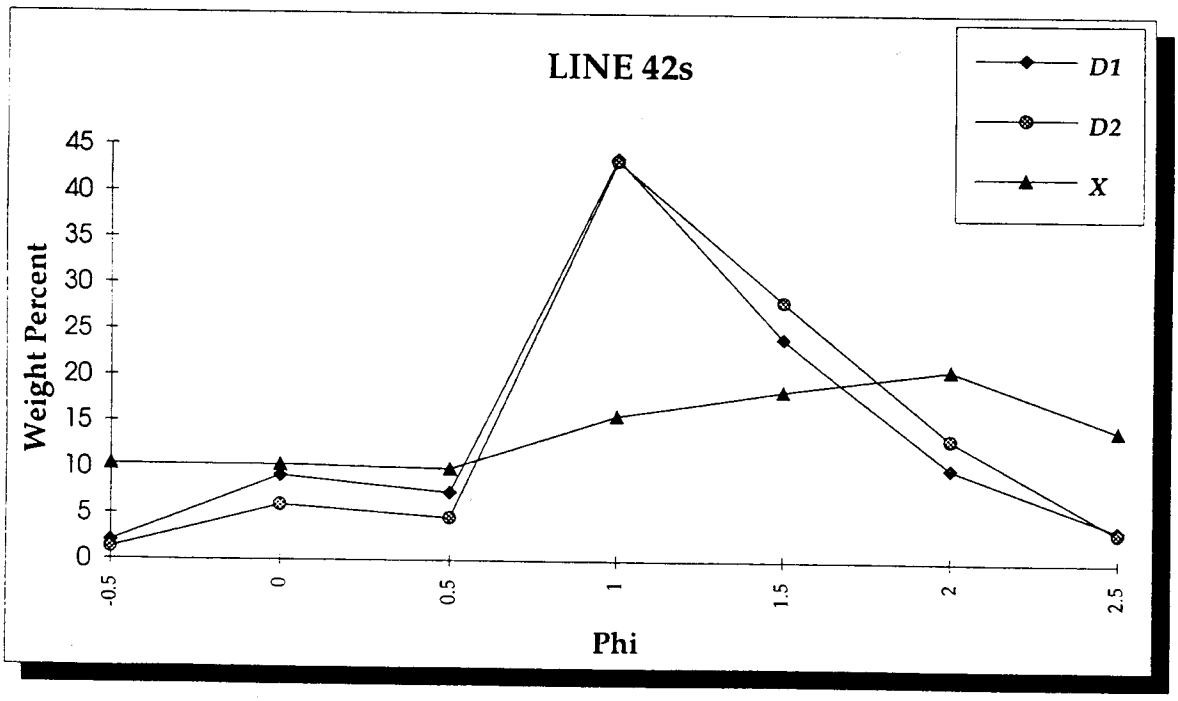


FIGURE A III - 6: D_1, D_2 and X for Line 42s (Environment 5; South Mitchell Island) showing net accretion down the transport path.

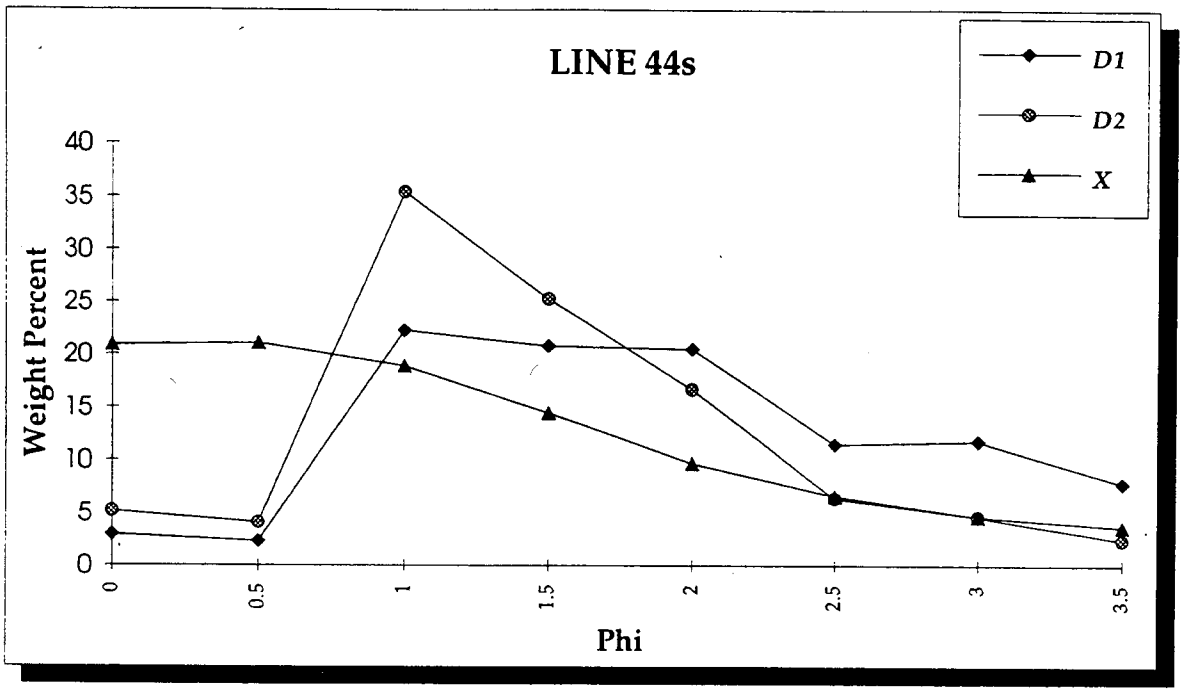


FIGURE A III - 7: D_1, D_2 and X for Line 44s (Environment 6; Middle Arm). The X-distribution is indicative of net erosion.

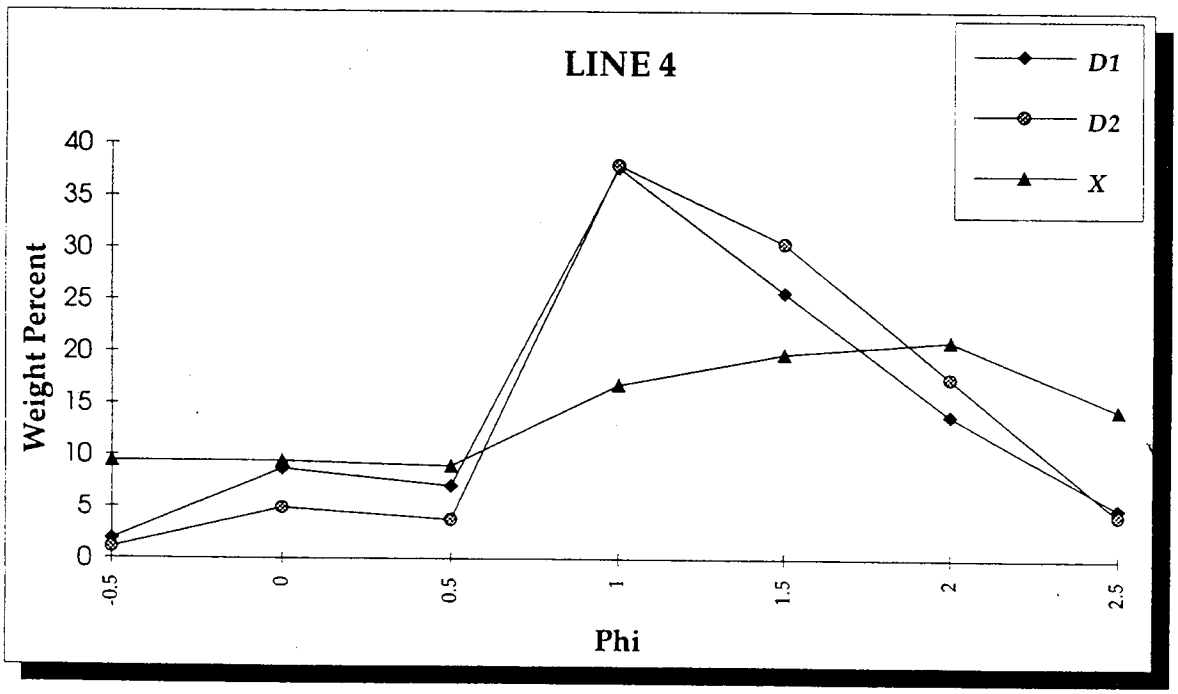


FIGURE A III - 8: D_1, D_2 and X for Line 4s (Environment 7; Western North Arm) showing net accretion down the transport path.

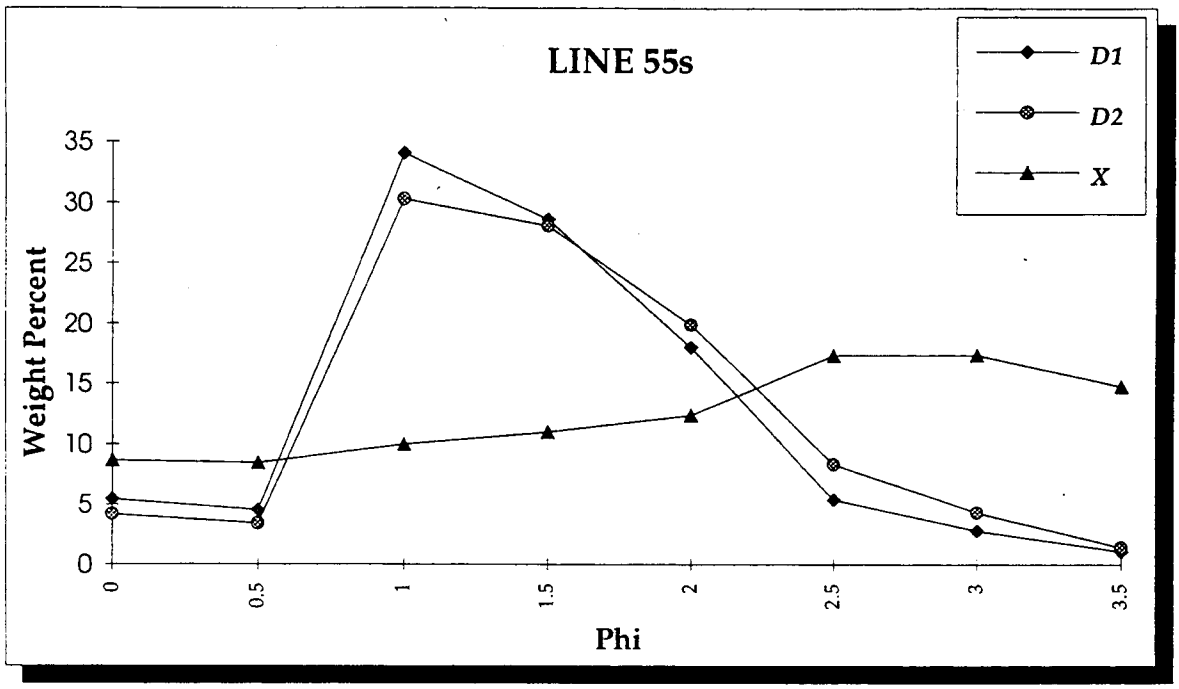


FIGURE A III - 9: D_1, D_2 and X for Line 55s (Environment 8; City Reach, Annacis Channel) showing net accretion.

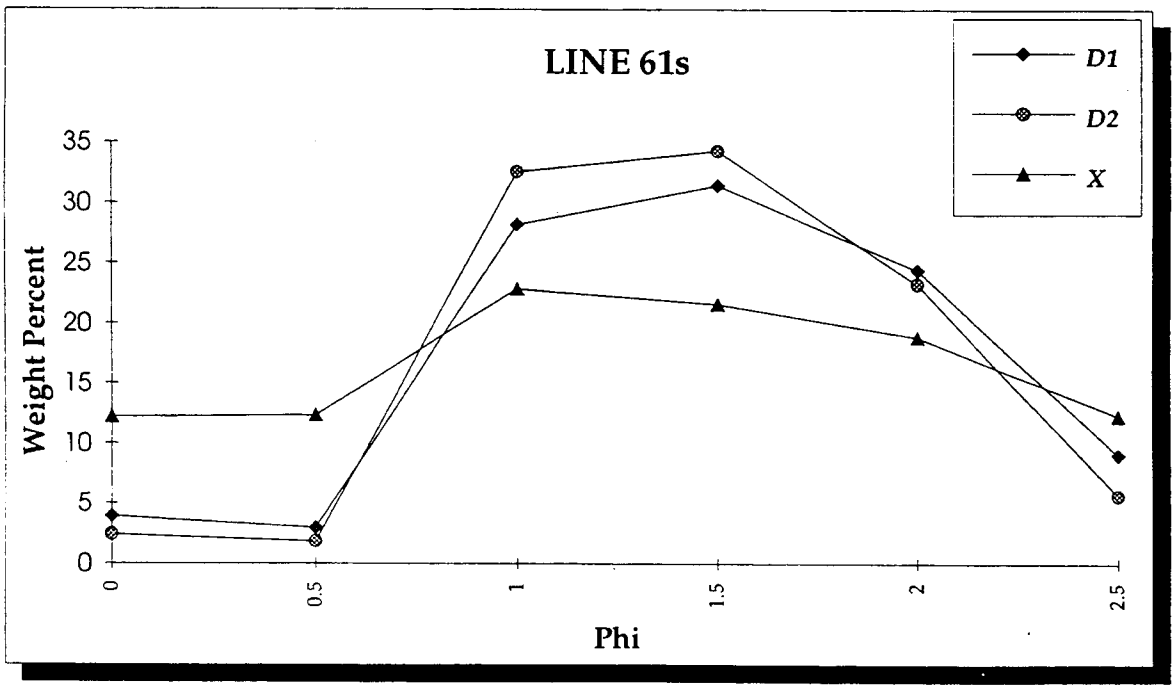


FIGURE A III - 10: D_1, D_2 and X for Line 61s (Environment 9; Gravesend Reach). The X-distribution indicates net erosion.

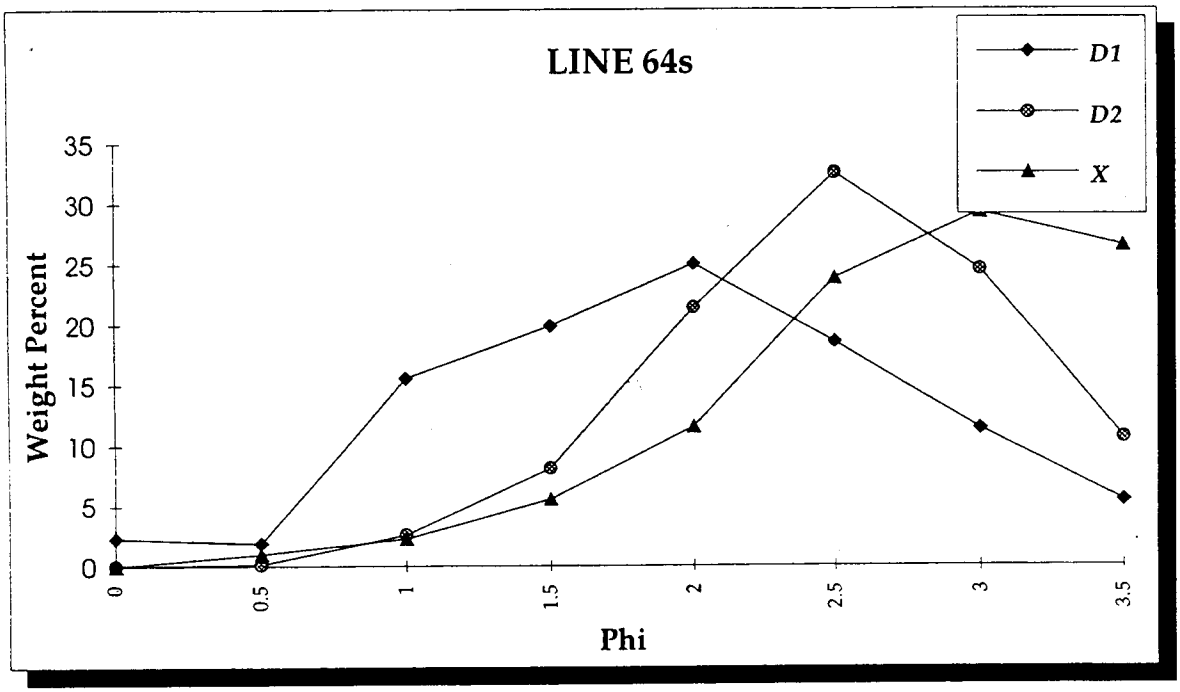


FIGURE A III - 11: D_1, D_2 and X for Line 64s (Environment 9; Gravesend Reach) showing net accretion down the transport path.

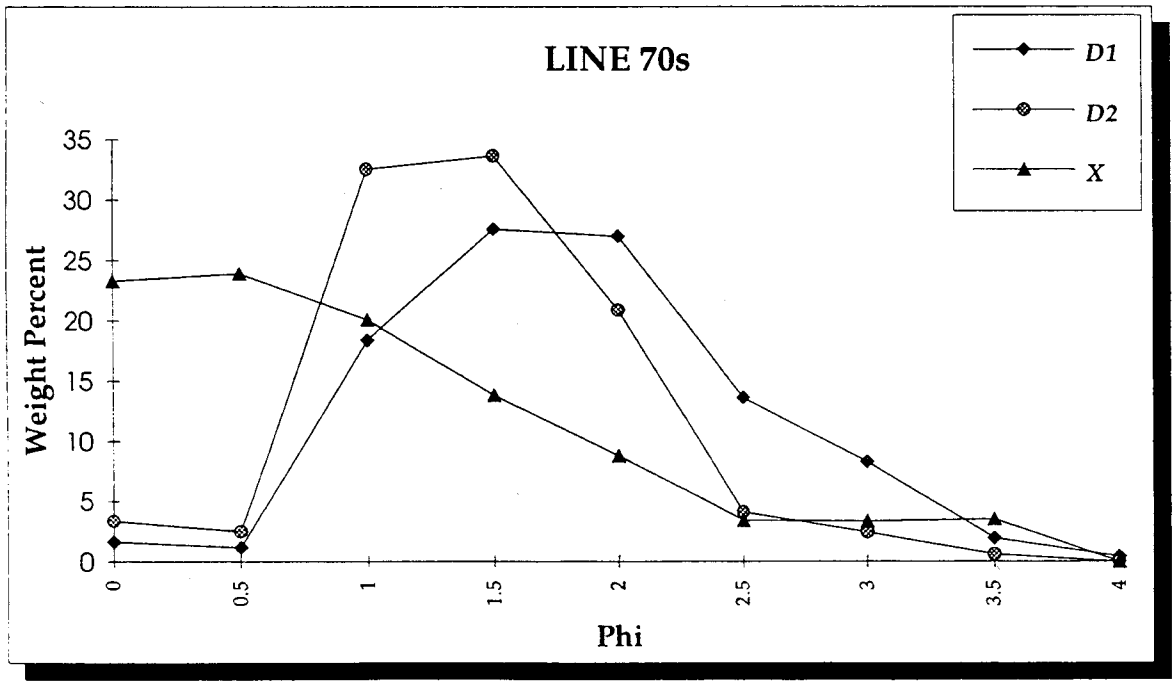


FIGURE A III - 12: D_1, D_2 and X for Line 70s (Environment 10; Woodward Reach). The x-distribution shows net erosion down the transport path.

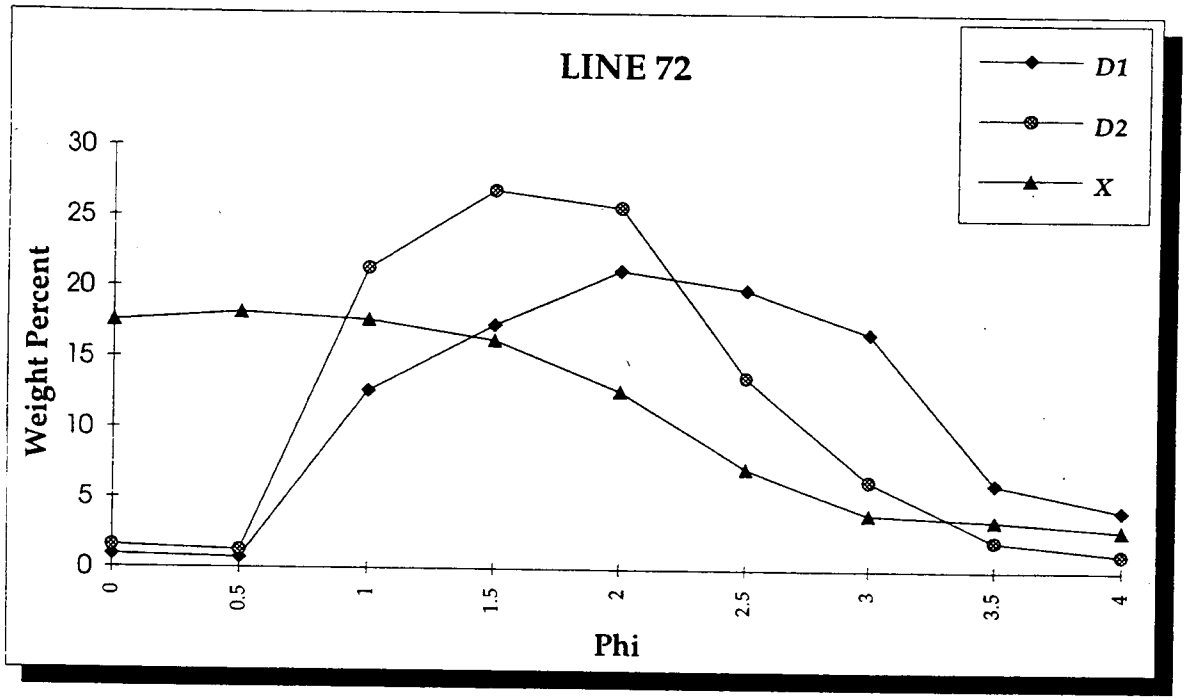


FIGURE A III - 13: D_1, D_2 and X for Line 72s (Environment 11; Ladner Reach/ Canoe Passage/ Sea Reach) showing net erosion.

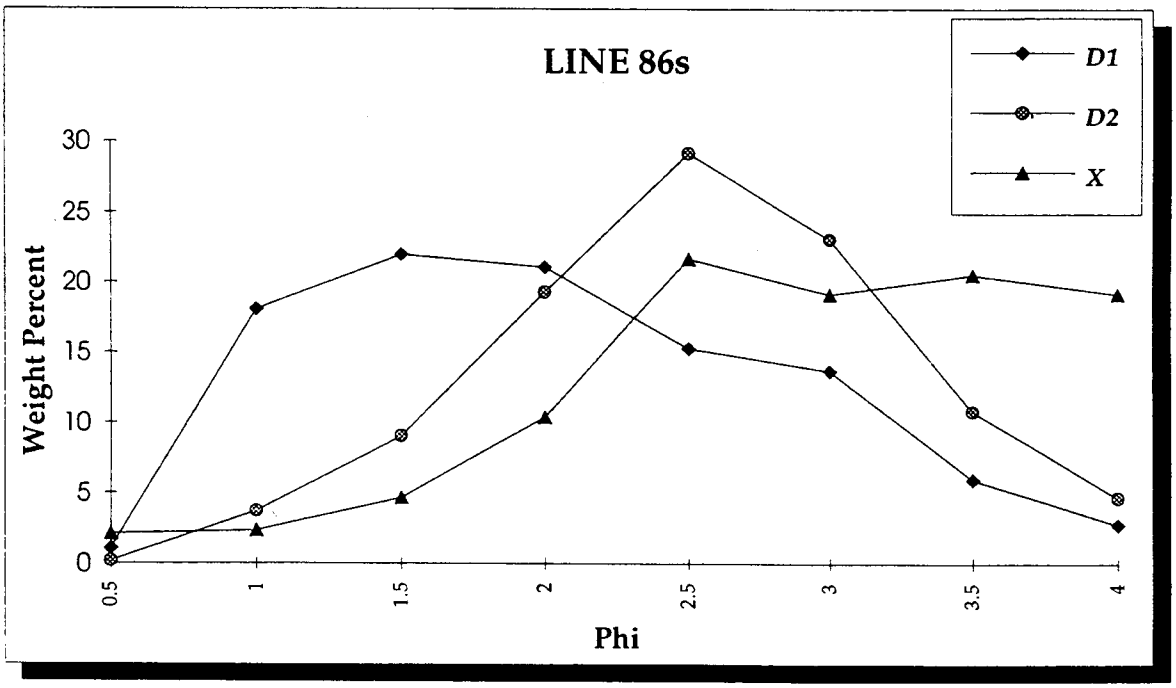


FIGURE A III - 14: D_1, D_2 and X for Line 86s (Environment 12; Steveston Bend). The X-distribution shows net accretion.

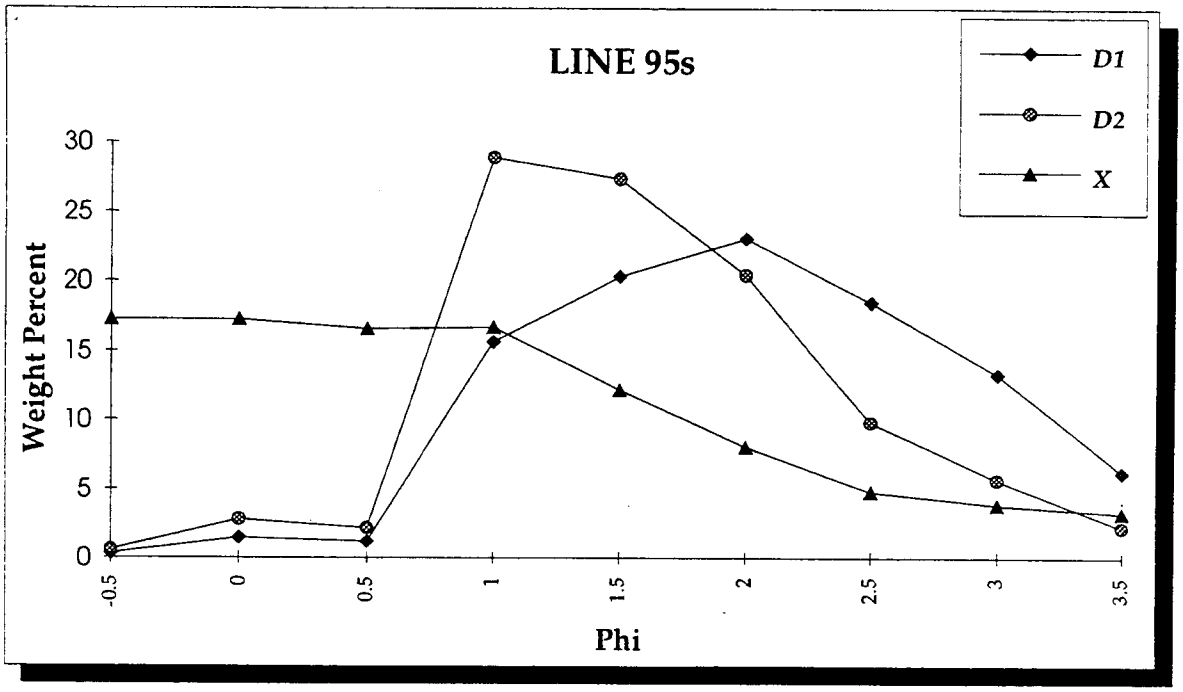


FIGURE A III - 15: D_1, D_2 and X for Line 95s (Environment 12; Steveston Bend) showing net erosion next to the Steveston Jetty.

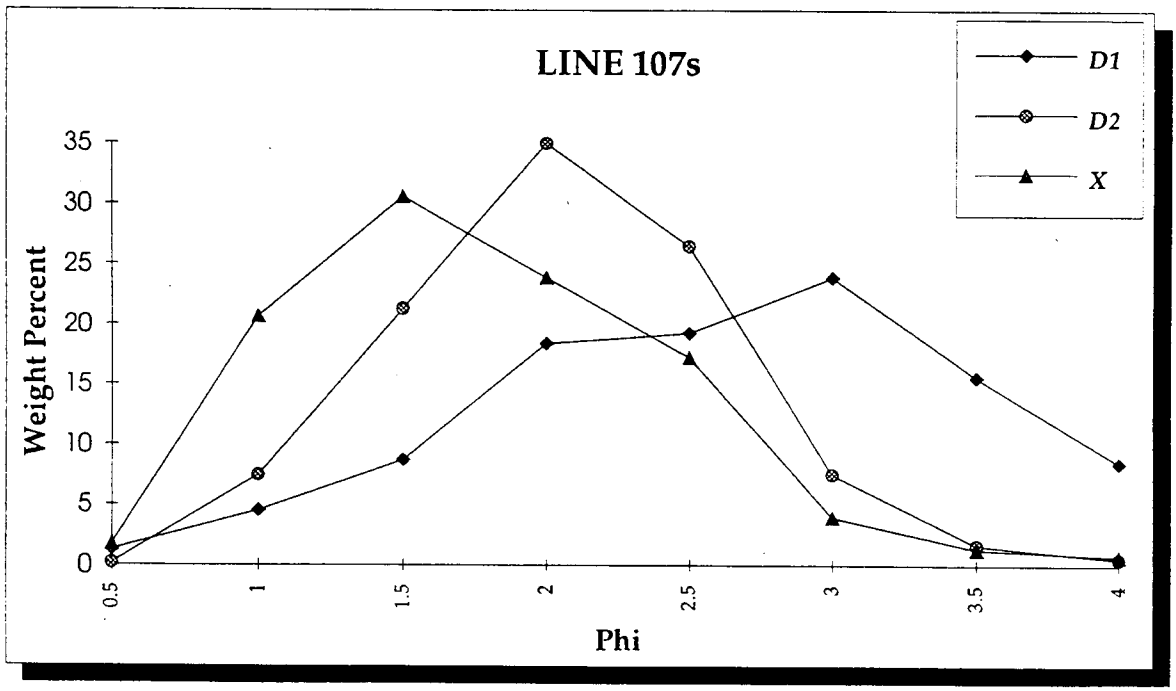


FIGURE A III - 16: D_1, D_2 and X for Line 107s (Environment 13; Roberts Bank/ Delta Foreslope) showing net erosion along the transport path.

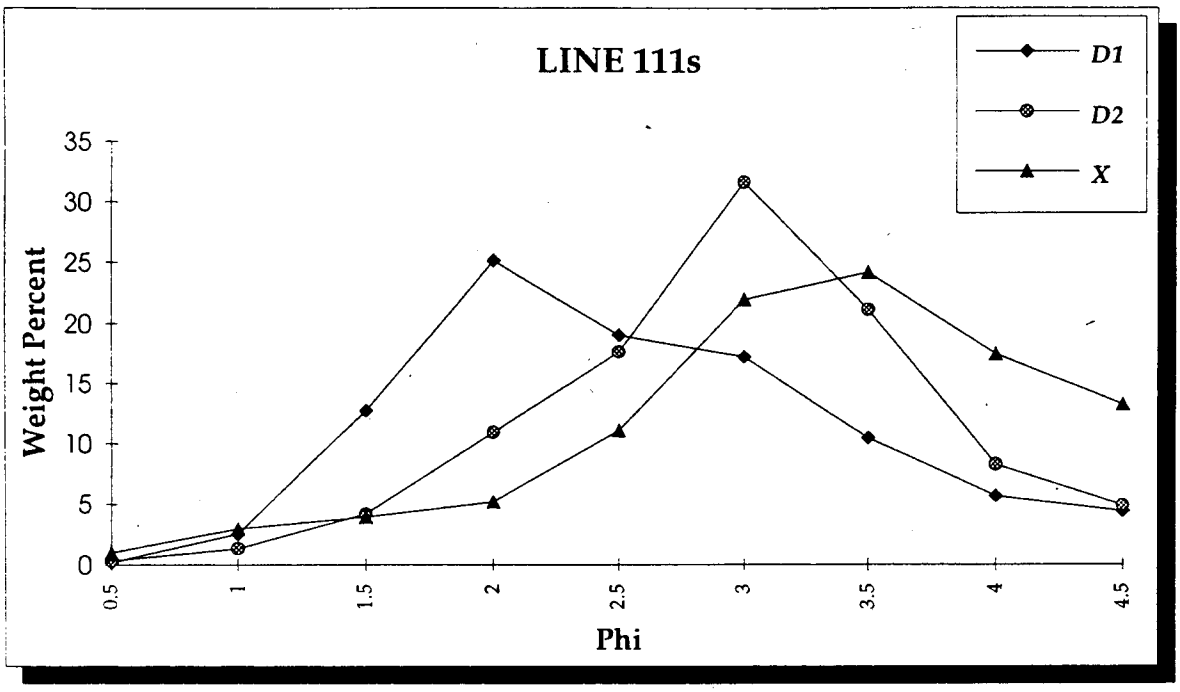


FIGURE A III - 17: D_1, D_2 and X for Line 111s (Environment 14; Westshore Terminals Intertidal flat) showing accretion.

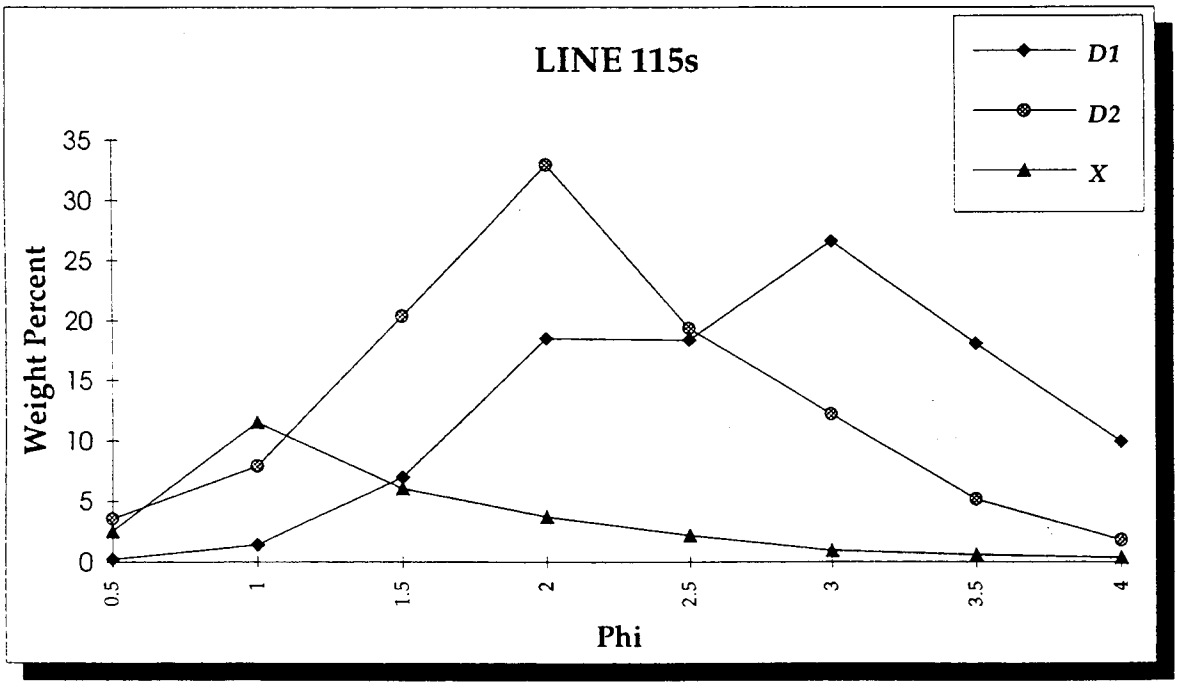


FIGURE A III - 18: D_1, D_2 and X for Line 115s (Environment 14; westshore Terminals Intertidal Flat) showing net erosion near low water.

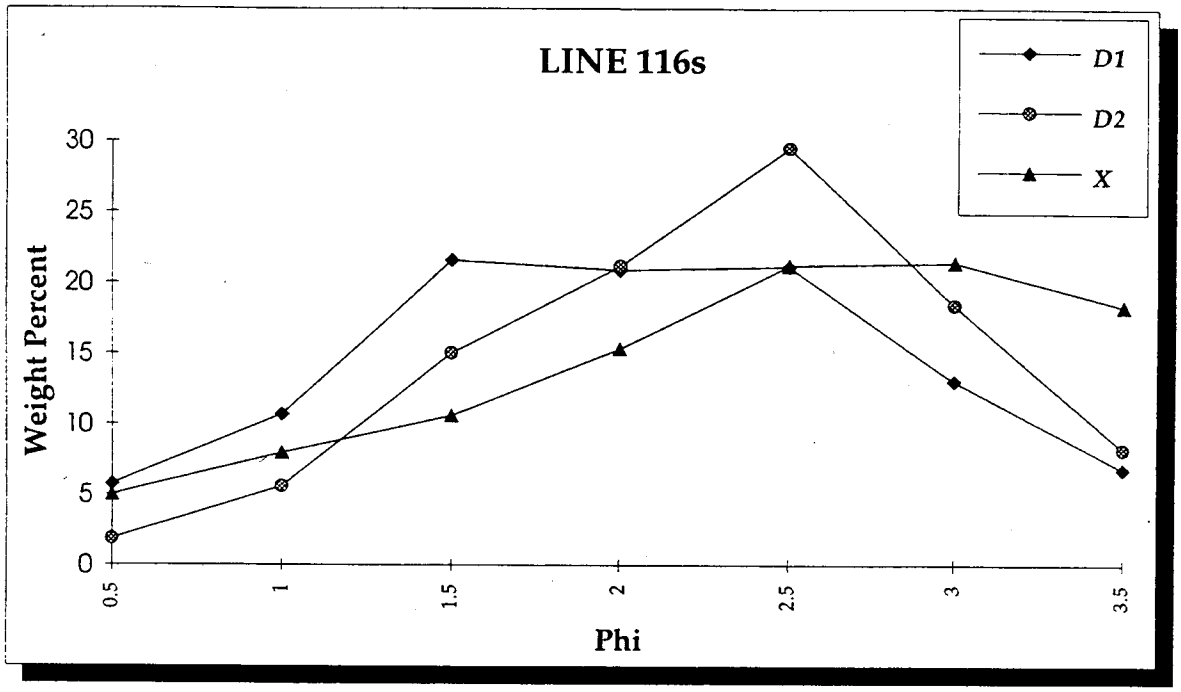


FIGURE A III - 19: D_1, D_2 and X for Line 116s (Environment 15; Tsawwassen Terminal Intertidal flat) showing net accretion.

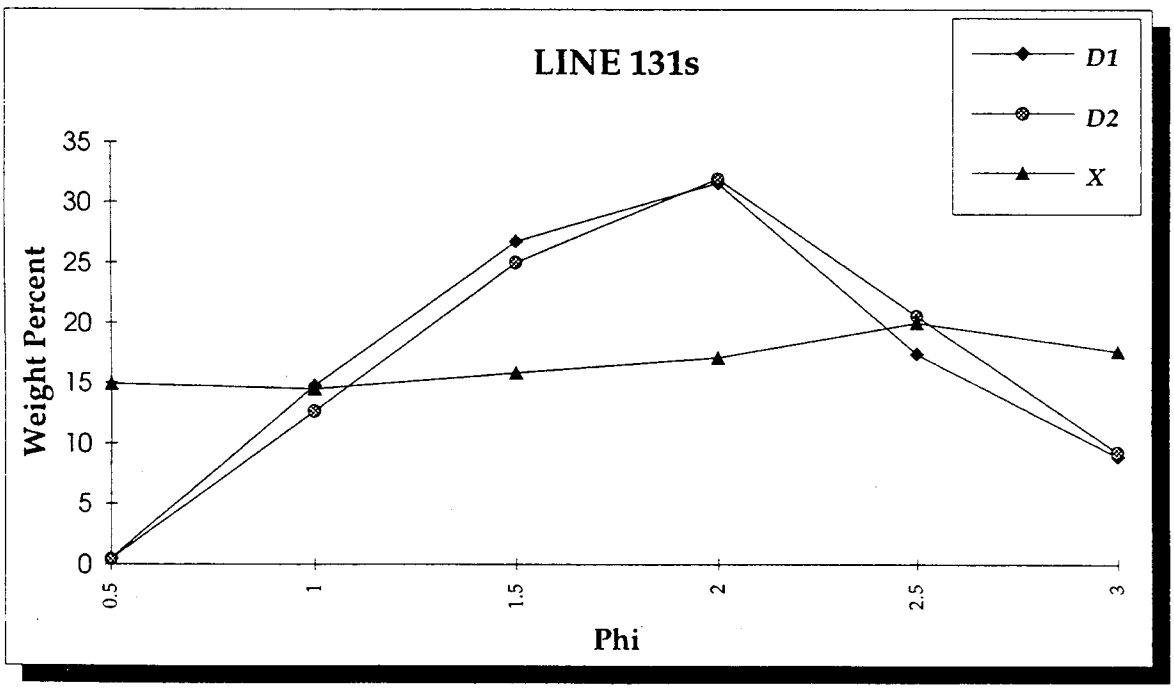


FIGURE A III - 20: D_1, D_2 and X for Line 131s (Environment 16; Southern Roberts Bank). The trends are mixed case but net accretion is favoured.

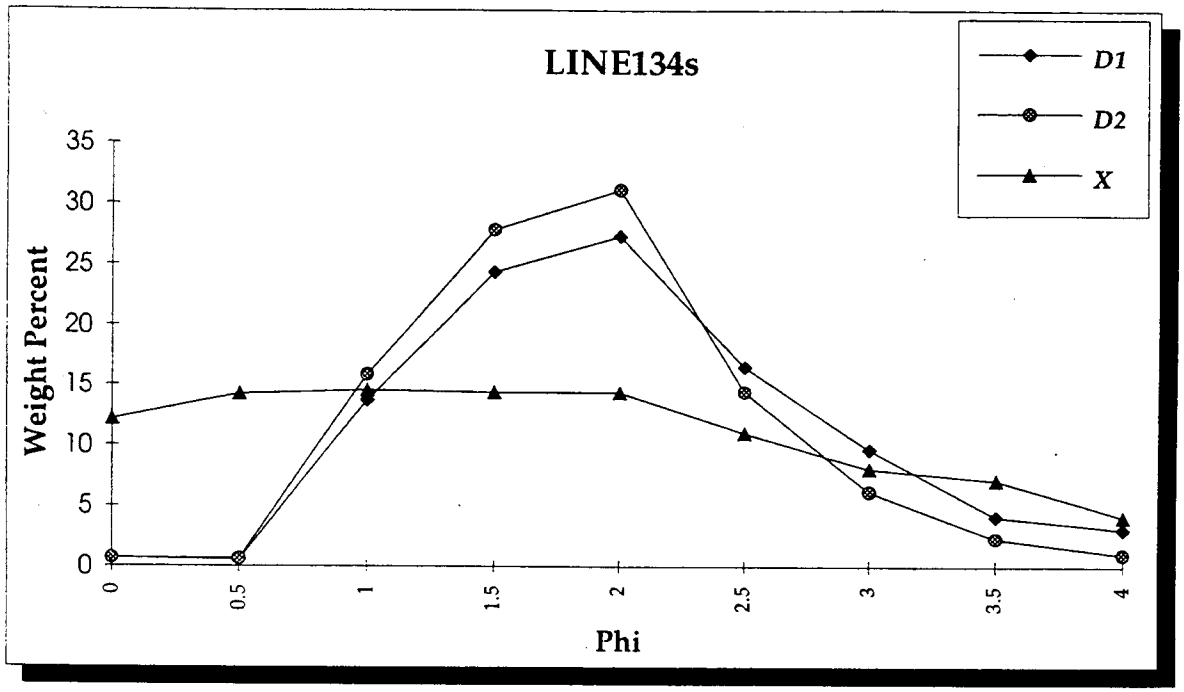


FIGURE A III - 21: D_1, D_2 and X for Line 134s (Environment 16; Southern Roberts Bank). The trends are mixed case with the dominant trend showing dynamic equilibrium.

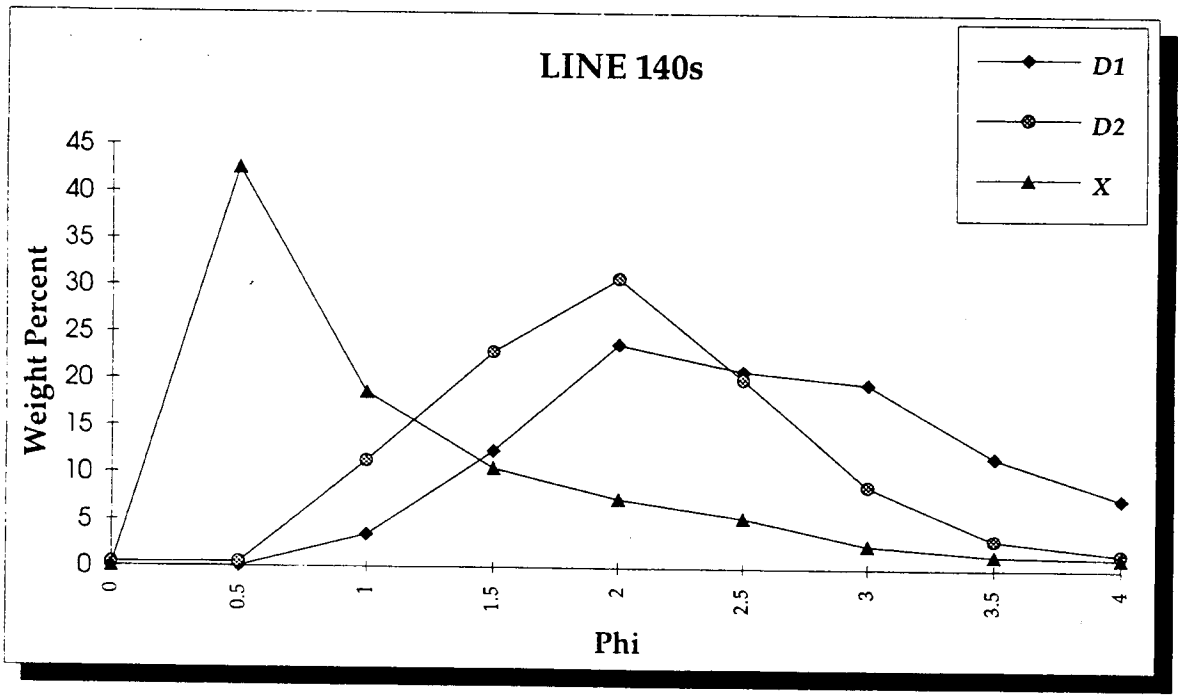


FIGURE A III - 22: D_1, D_2 and X for Line 140s (Environment 17; Northern Roberts Bank) showing net erosion.

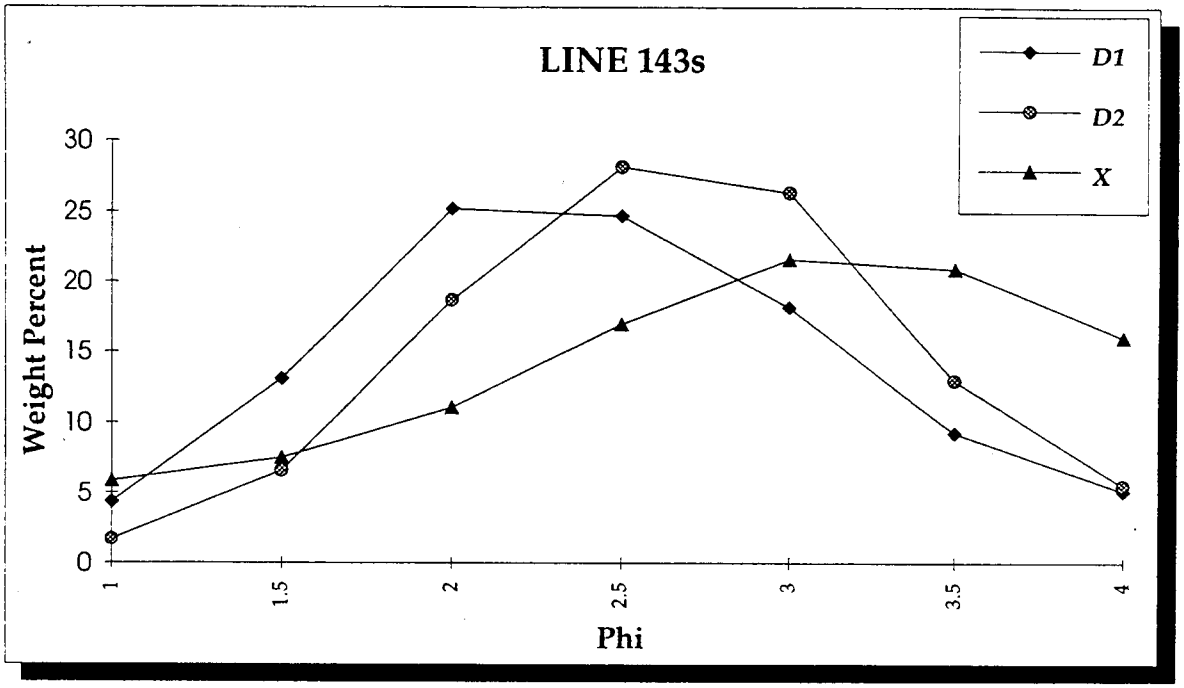


FIGURE A III - 23: D_1, D_2 and X for Line 143s (Environment 17; Northern Roberts Bank) showing net accretion.

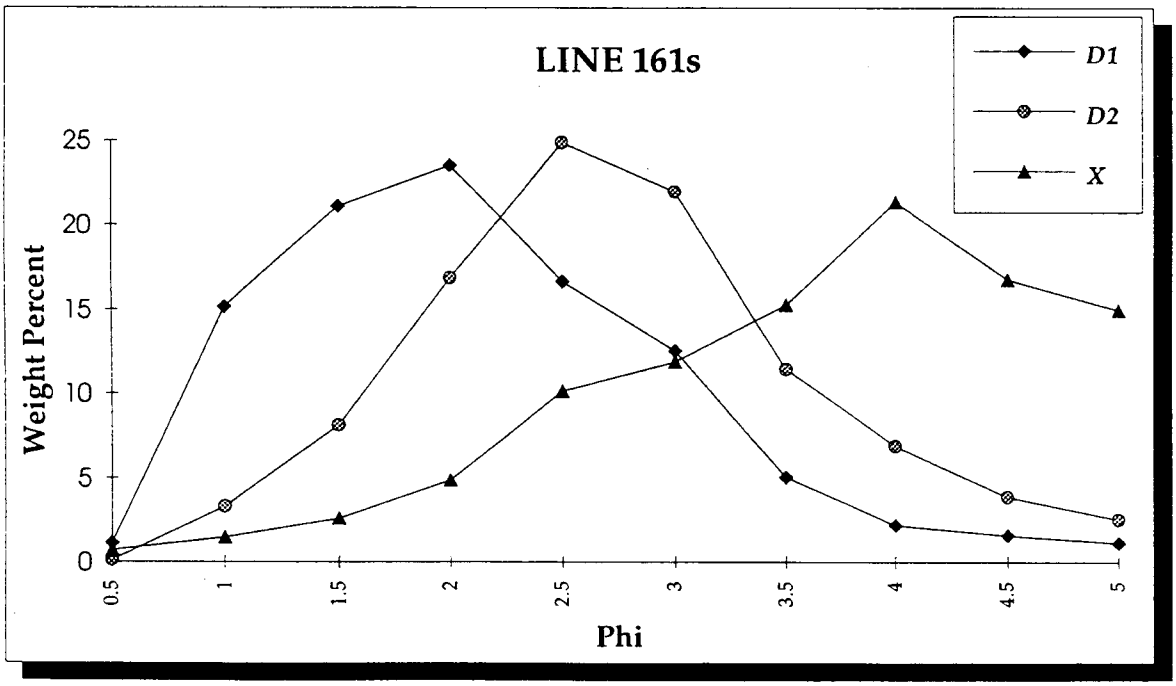


FIGURE A III - 24: D_1, D_2 and X for Line 161s (Environement 18; Sturgeon Bank) showing net accretion.

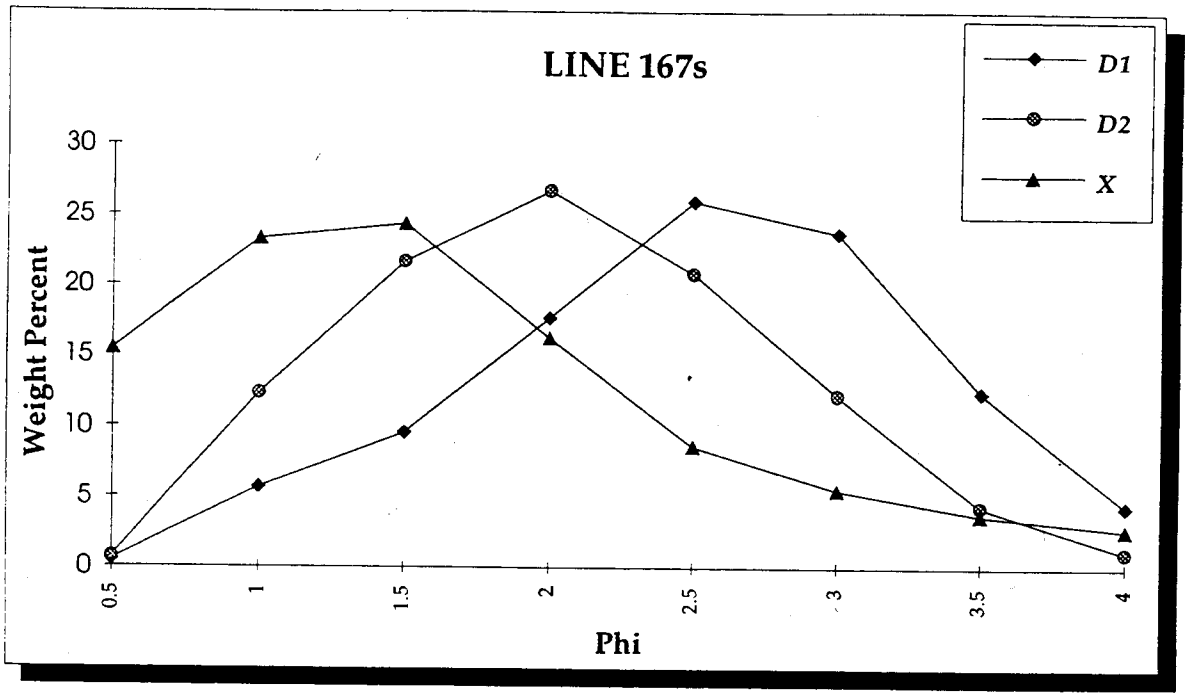


FIGURE A III - 25: D_1, D_2 and X for Line 167s (Environment 18; Sturgeon Bank). The trends are mixed case with the dominant trend showing net erosion.

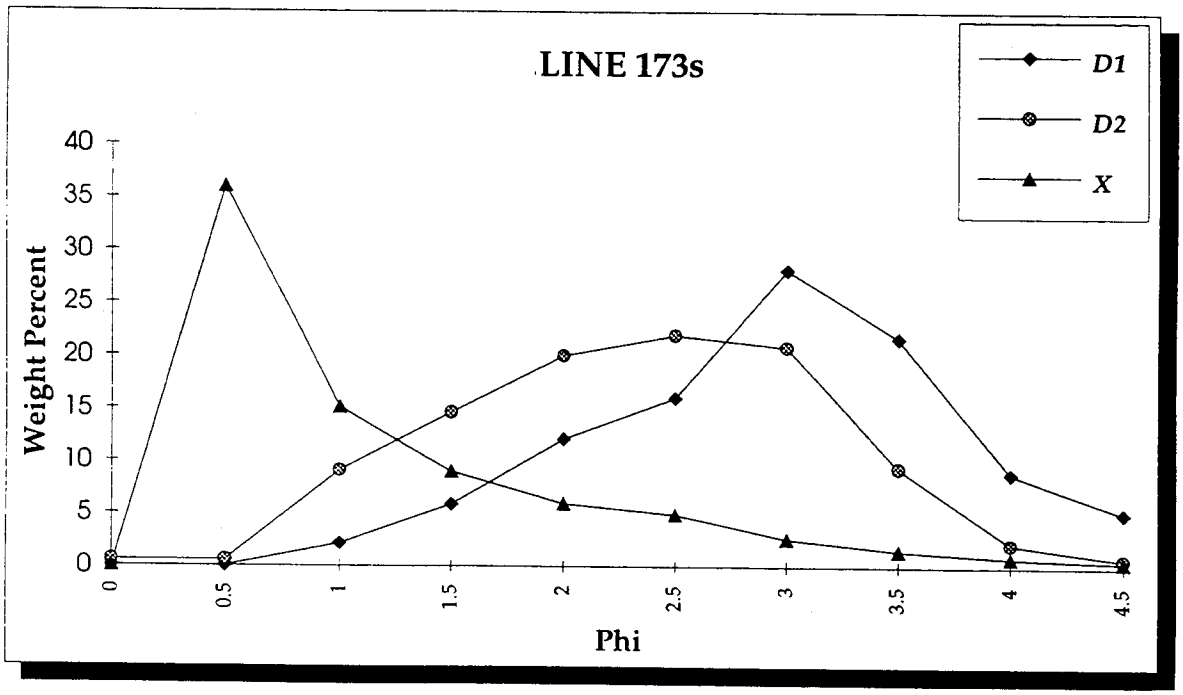


FIGURE A III - 26: D_1, D_2 and X for Line 173s (Environment 19; Iona Intertidal flat) showing net erosion.

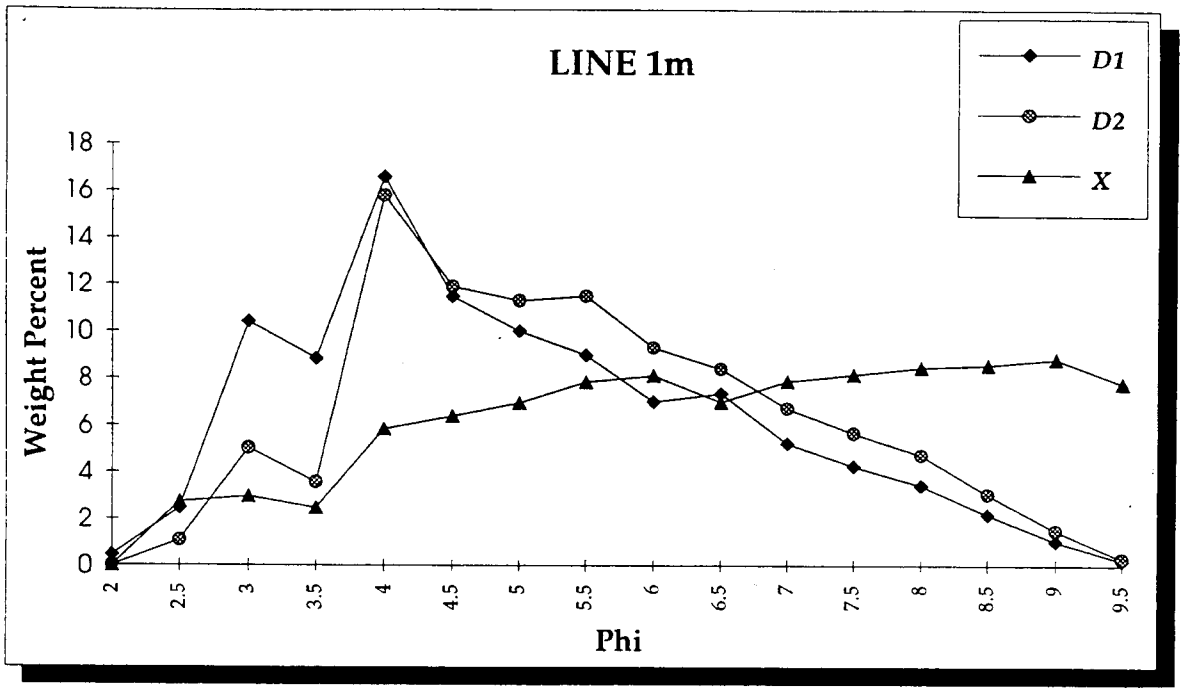


FIGURE A III - 27: D_1, D_2 and X for Line 1m (Environment 2; Coquitlam River/ Pitt River) showing net accretion.

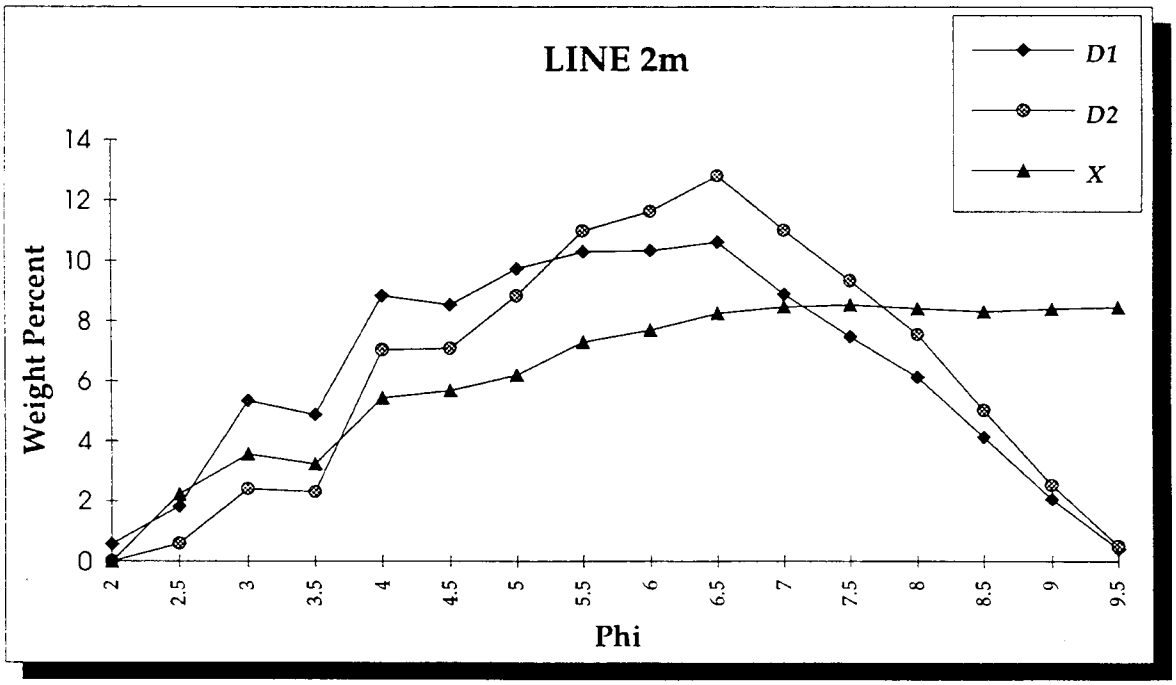


FIGURE A III - 28: D_1, D_2 and X for Line 2m (Environment 4; Queen's Reach/ Sapperton Channel) showing total deposition occurring in "Queensborough Backwater".

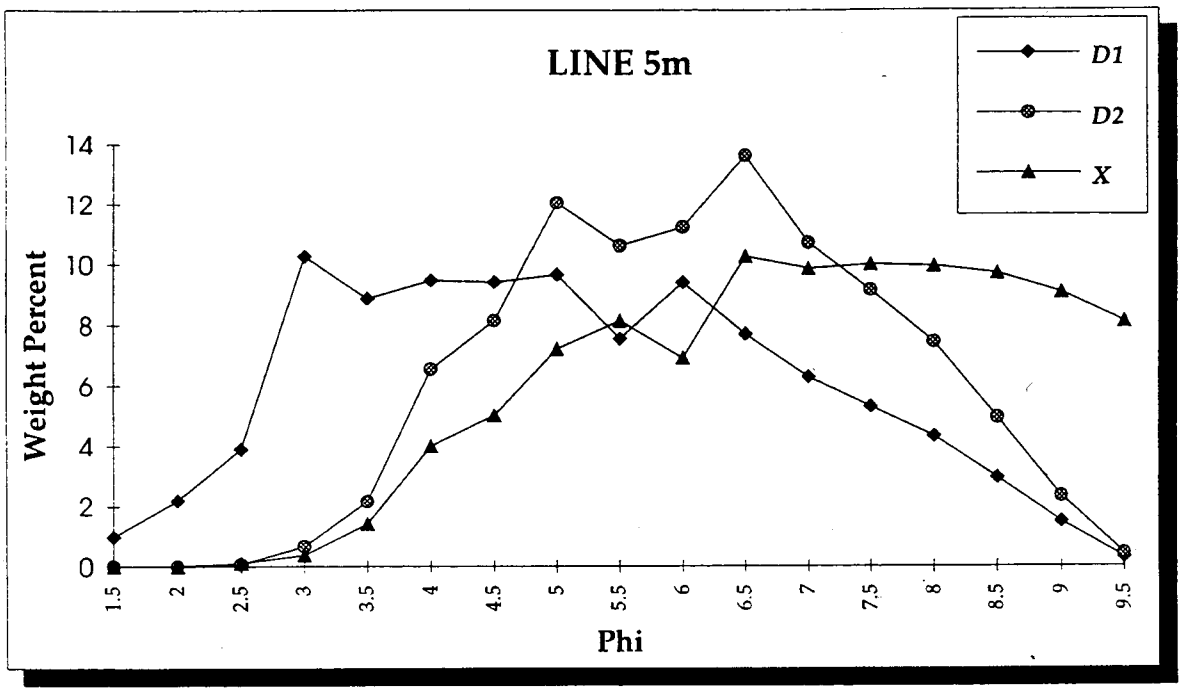


FIGURE A III - 29: D_1, D_2 and X for Line 5m (Environment 6; Middle Arm) showing net accretion.

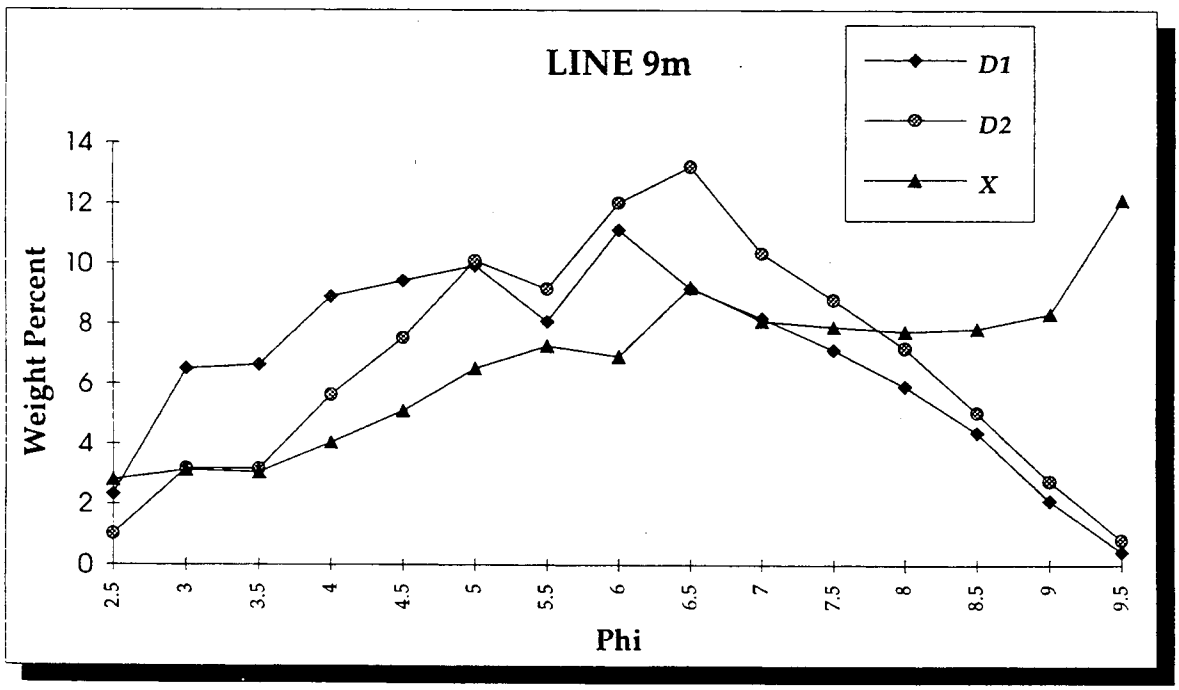


FIGURE A III - 30: D_1, D_2 and X for Line 9m (Environment 7; Western North Arm) showing total deposition in McDonald Slough.

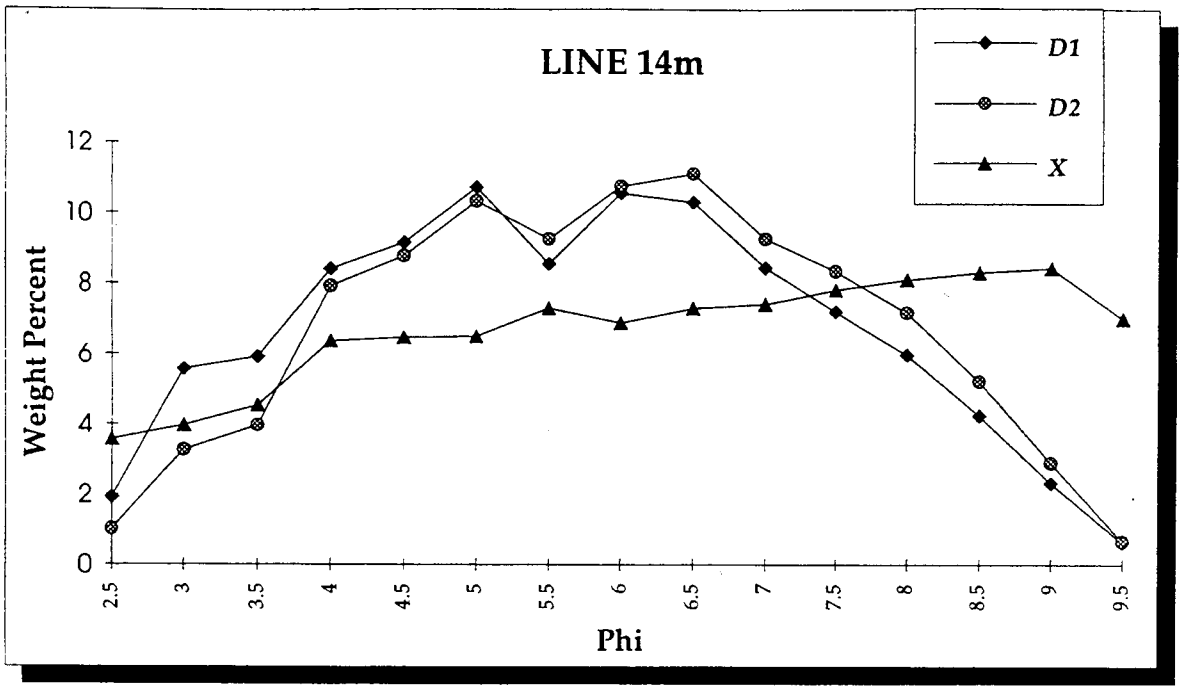


FIGURE A III - 31: D_1, D_2 and X for Line 14m (Environment 7; Western North Arm) showing net accretion.

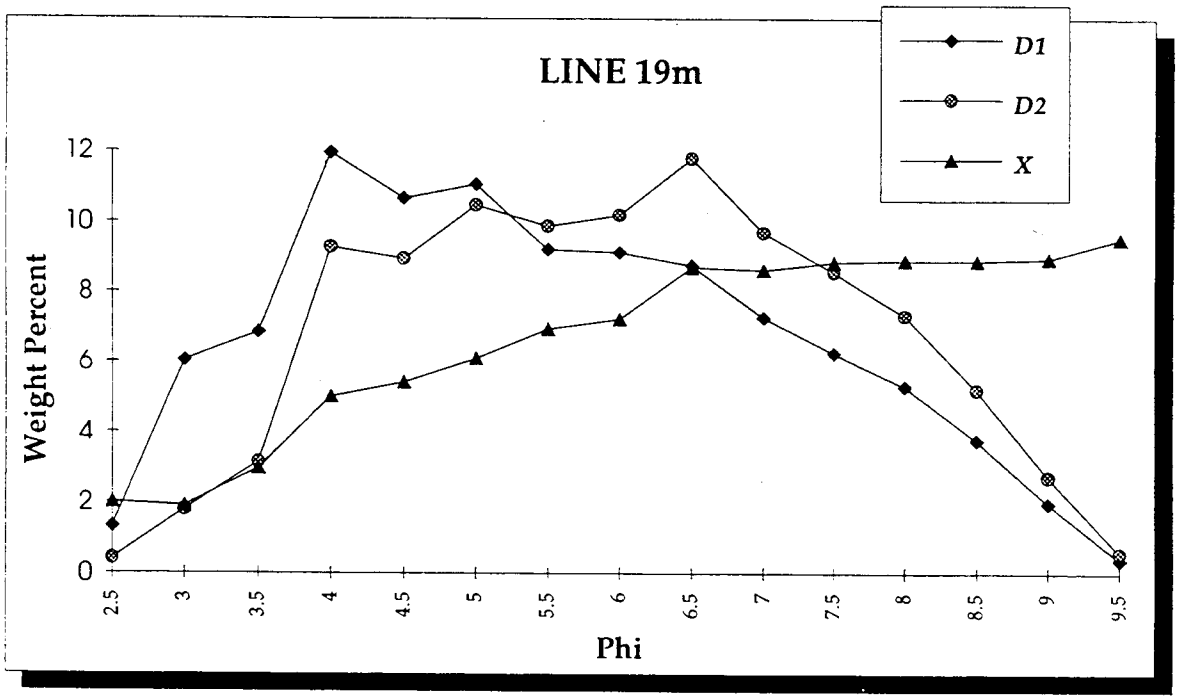


FIGURE A III - 32: D_1, D_2 and X for Line 19m (Environment 8; City Reach/ Annacis Channel) showing total deposition in Annacis Channel.

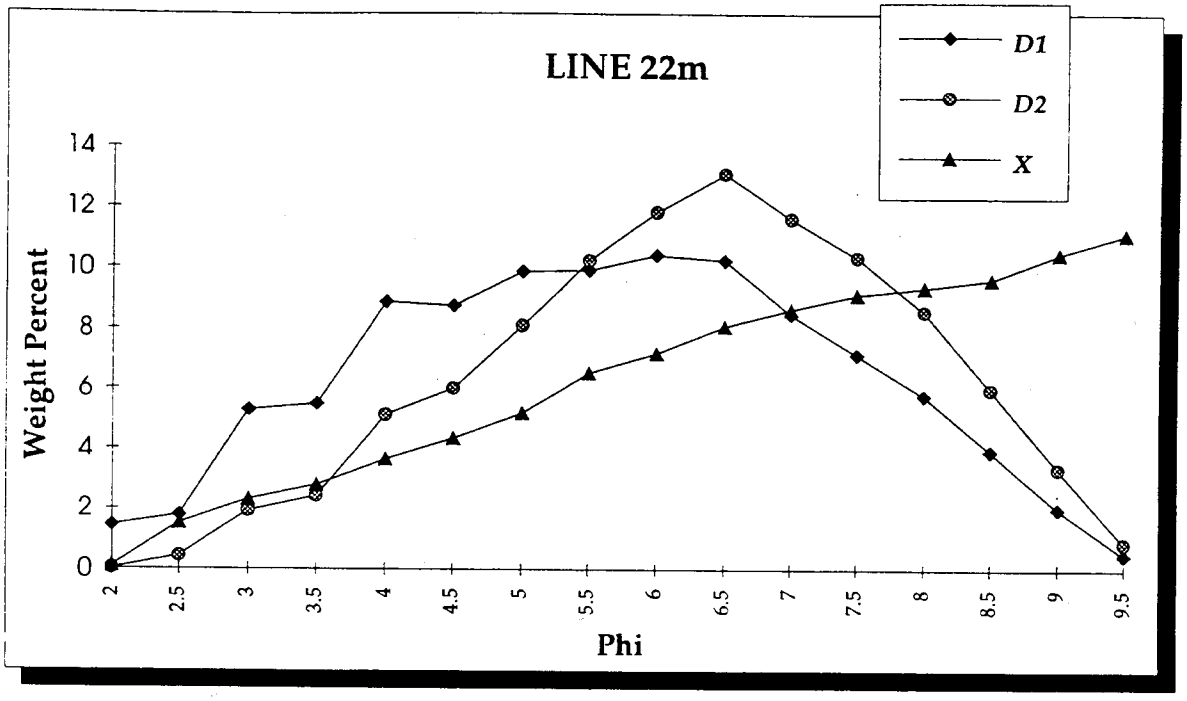


FIGURE A III - 33: D_1, D_2 and X for Line 22m (Environments 9,10,11 and 16) showing total deposition in Deas Slough.

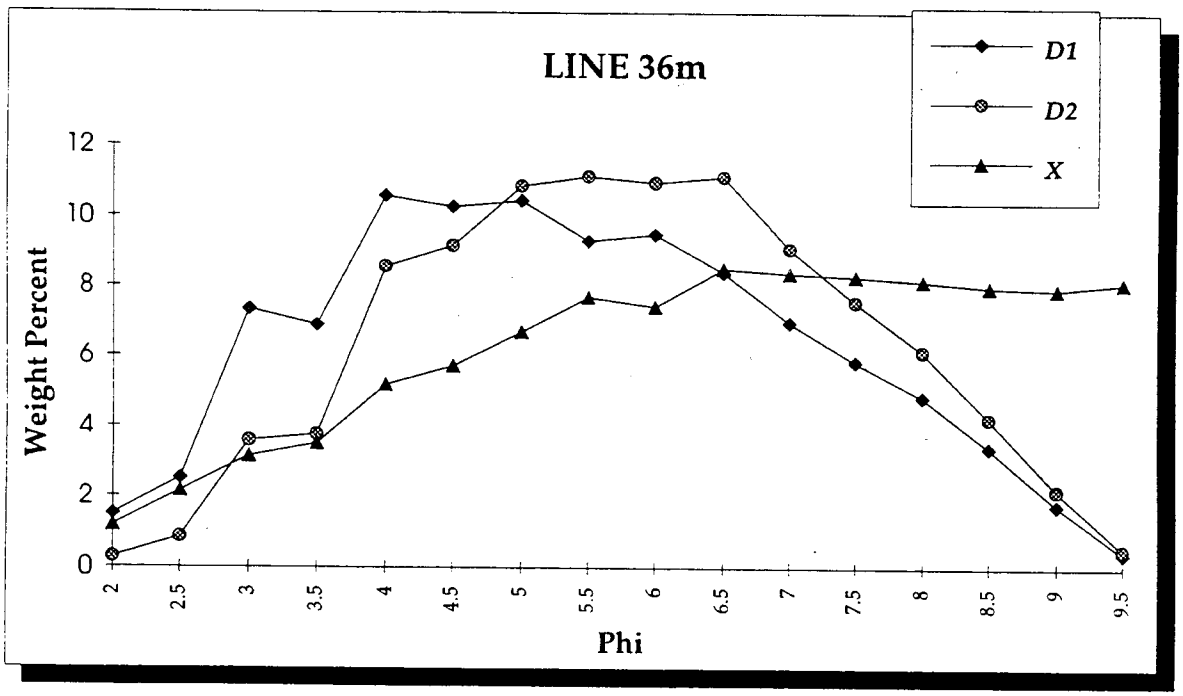


FIGURE A III - 34: D_1, D_2 and X for Line 36m (environments 9,10,11 and 16) showing net accretion of mud through Canoe Passage.

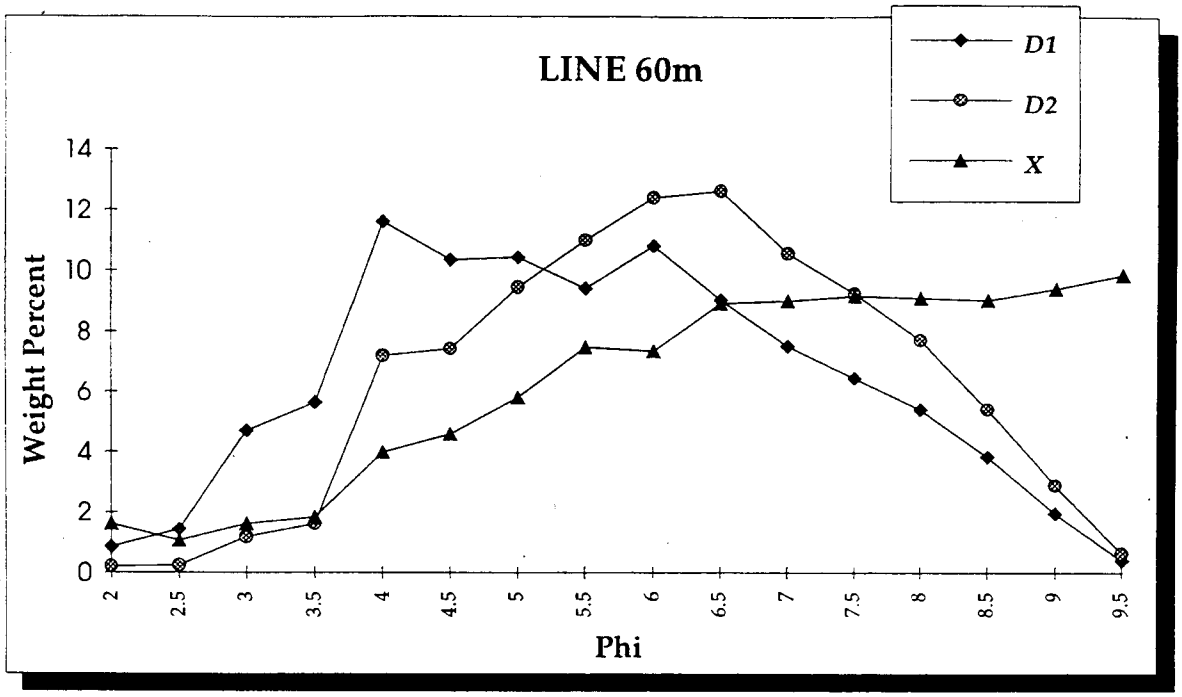


FIGURE A III - 35: D_1, D_2 and X for Line 60m (Environment 17; Northern Roberts Bank) showing total deposition along the fringe marsh.

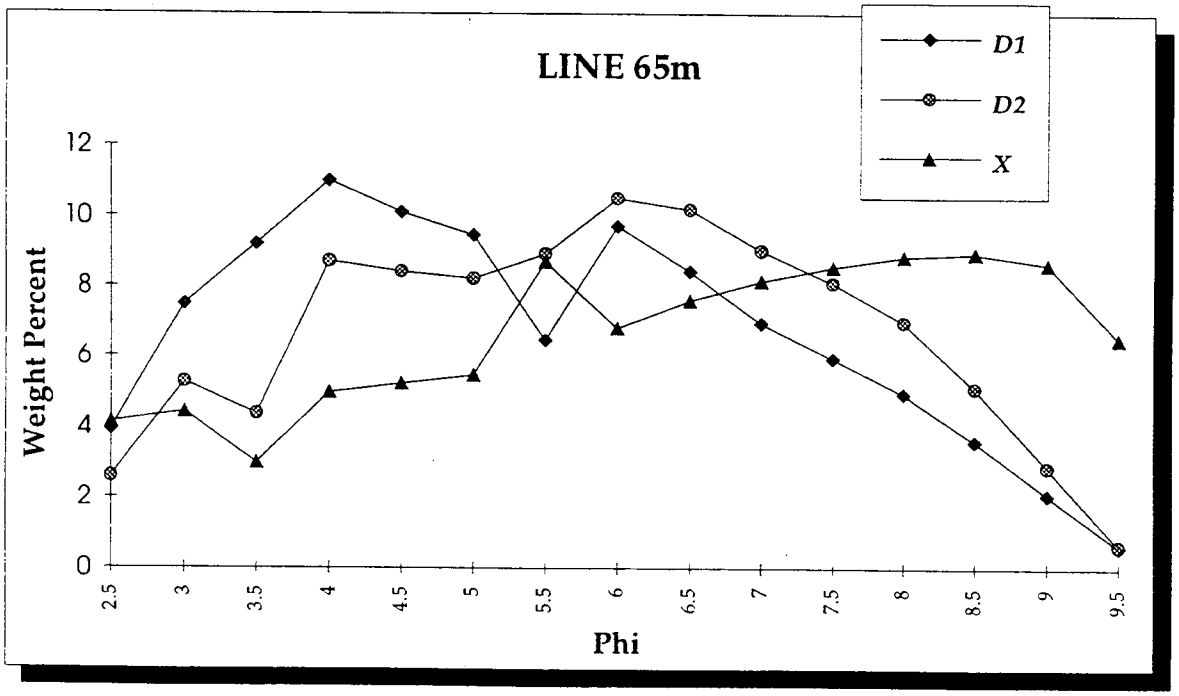


FIGURE A III - 36: D_1, D_2 and X for Line 65m (Environment 17; Northern Roberts Bank) showing net accretion.

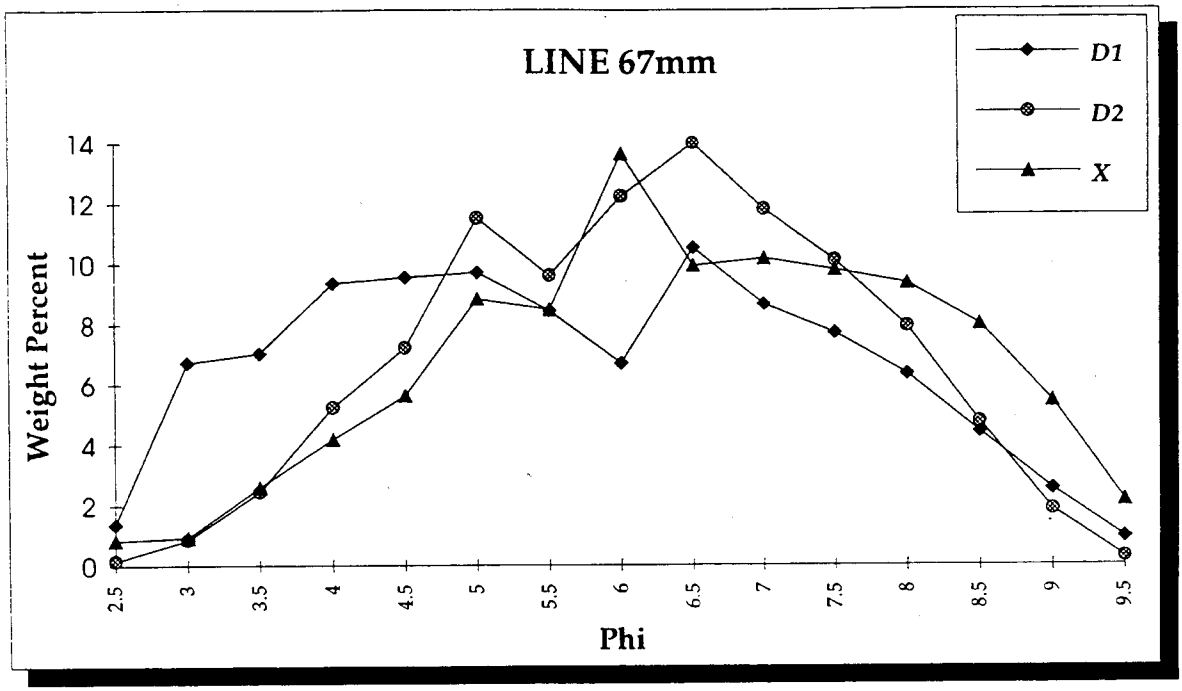


FIGURE A III - 37: D_1, D_2 and X for Line 67m (Environment 18; Sturgeon Bank) showing dynamic equilibrium.

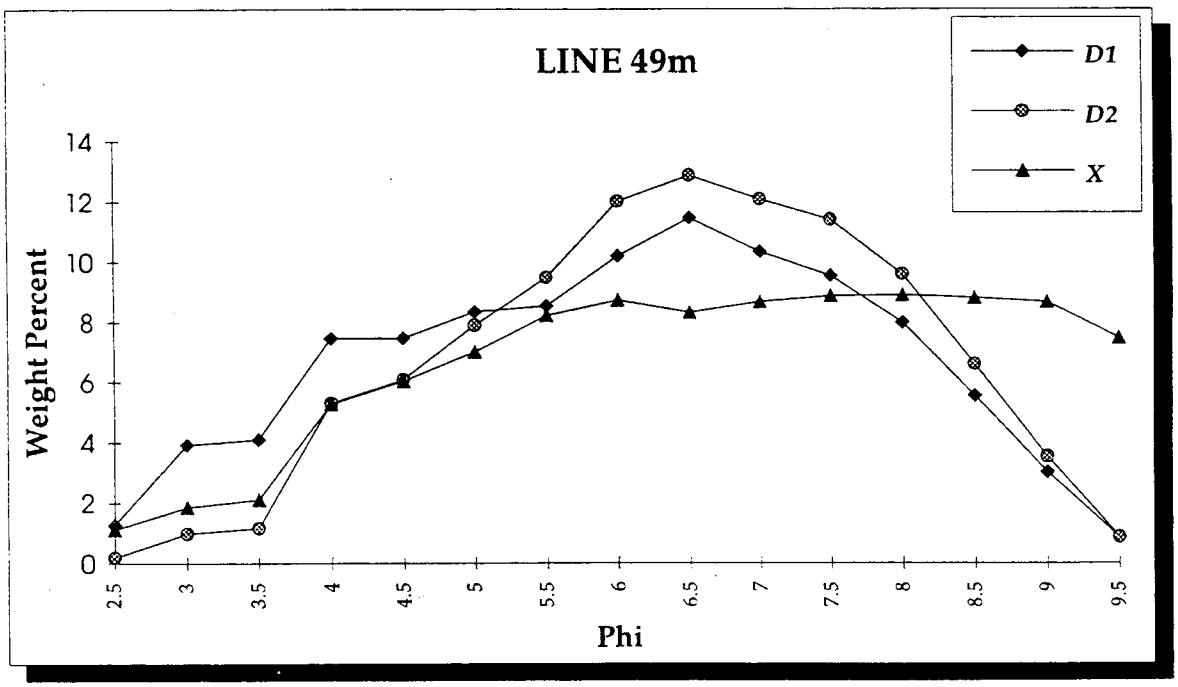


FIGURE A III - 38: D_1, D_2 and X for Line 49m (Environment 20; Delta Foreslope) showing net accretion.

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