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THE SEDIMENTOLOGY OF UNCONSOLIDATED DELTAIC AND AEOLIAN SEDIMENTS EAST OF DUNNVILLE, ONTARIO

BY

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The conviction that one's own hypothesis is right

is frequently the mark

of one who is poorly informed about alternatives.

-H.G. Reading, 1978.

ABSTRACT

Surficial sediments east of Dunnville, Ontario representing a limited deltaic/lacustrine/aeolian system are investigated with the aim of defining and interpreting their geological history by means of examining their sedimentology and interrelationships. The Folk and Ward grain size statistics of samples from the area were calculated. These sample parameters were then plotted on maps to determine regional patterns. The strongest pattern observed was one of distinct fining to the east, away from the sand source. Aeolian deposits were found to be better sorted than the surrounding sediments. The grain size parameter values were also plotted on bivariate graphs in an attempt to separate the samples according to depositional environment. This exercise met with little success, as most of the sediments sampled in the area have similar grain size parameters. This is believed to be because the sediment sources for the different environments (delta, distal delta, aeolian dune) are intimately related, to the point that most dunes appear to have been sourced from immediately local sediments. It is postulated that in such a small sedimentological sub-system, sediments were not involved in active transport for a length of time sufficient for the material to come to equilibrium with its transporting medium. Thus, few distinctive patterns of parameters were developed that would enable one to differentiate between various environments of deposition. The immaturity of many dune forms and the immaturity of mineralogical composition of all deposits support the above hypothesis of limited transport time.

Another hypothesis proposed is that each geologically or geographically distinct area or "sub-system" may have its own "signature" of grain size relationships as plotted on bivariate graphs. Thus, the emphasis, concerning graphs of this type, should not be placed on attempting to differentiate between various environments of deposition, but rather on investigating the interrelationships between samples and environments within that "sub-system".

Through the course of this investigation, the existence of delta plain distributary channels in the thesis area is suggested, and the discovery of significantly different sub-units within the Dunnville dune sediments is documented. It is inferred by reference to other authors interpretations of the glacial history of the area, that the time of effective aeolian activity in the Dunnville area was between 12,300 to 12,100 years B.P.

ACKNOWLEDGEMENTS

Through the course of this investigation, a great number of people have contributed in different ways to its completion. I would like to thank my primary advisor, Dr. J. Terasmae, for guidance and financial assistance; Dr. J. Menzies for suggestions and constructive criticism; my family and friends for help and support, both in the field and in the lab, especially my parents and my wife, Pam who also assisted with much of the drafting and editing; my field and lab assistants, Ed Walker and John Barnsley for cooperating even when my motives seemed less than sane; Ms. Janet Pinder for the XRF analyses; Hilary Plint, Paul Bazinet and Duncan Robertson for offering constructive criticism; the land owners in the thesis area for cooperation and interesting conversations, particularly Mr. Gerry Bruulsema, who was kind enough to assist me by allowing continual access to his property and for operating a backhoe for trenching; John Fraser of the Ontario Ministry of Natural Resources; and the staff of the machine shop at Brock University for constructing and constantly maintaining the coring equipment.

Of note are certain employees of Petro-Canada in Calgary, who assisted me in various ways. These included Dr. Hugh Balkwill, Dr. Phillip Brown, Dr. Peter Dankers and Dr. Gordon Tebbutt for cooperation in arranging use of laboratory facilities and equipment; Sandra Long and Howard Van Der Hoef for advice and instruction in the use of laboratory equipment; Charles (Chuck) Savoie for overseeing the production of the X-radiographs and core photographs; and the Petro-Canada library staff for their excellent research services. Many thanks are also due Pat Fuller for her patience and diligence in typing this manuscript. Petro-Canada Inc. is thanked for financial assistance in reproduction costs.

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INTRODUCTION AND PREVIOUS WORK

Location and Preface

The area investigated in this thesis, located in and around the town of Dunnville, Ontario (Latitude 42°54'N, Longitude 79°37'W) (Fig. 1), was described by Chapman and Putnam (1966) as consisting of poorly drained sand, silt, and clay, and was interpreted by them as representing a delta of the Grand River built into a higher glacial lake phase of the Lake Erie basin. Their map of the physiography of the area shows a sand plain with very few sand dunes. Feenstra's (1972 and 1974) studies, however, reveal many more sand dunes in the area than Chapman and Putnam indicated.

In later work, Feenstra (1981) discusses the ancestral Grand River delta plain and associated sand dunes, elaborating somewhat on the sand dunes' history and composition. Feenstra's maps (1972 and 1974) were the primary incentive for investigating this area, as the author was previously unaware of such post-glacial aeolian systems in the Niagara Peninsula. Since much reference will be made to Feenstra's (1972, 1974) maps, they have been included here as Enclosures 3 and 4.

Part of the thesis area is covered by a preliminary map produced by the Ontario Institute of Pedology (Langman, 1978). This map shows a pattern of soil types similar to the outlines of surficial geology units indicated on Feenstra's (1972 and 1974) maps, particularly regarding the gross areal limits of the inland aeolian dunes. The basic outline of Quaternary history, included with this map, is based on Feenstra's (1972, 1974 and 1981) summaries, and so provide no additional data in that respect.

Since Feenstra's (1972 and 1974) studies were concerned with reconnaissance mapping of surficial deposits, certain problems remain unsolved. For example, limited sedimentological work was done, and no absolute age dates were determined. As well, dunes seem to have been mapped on a purely morphological basis, which

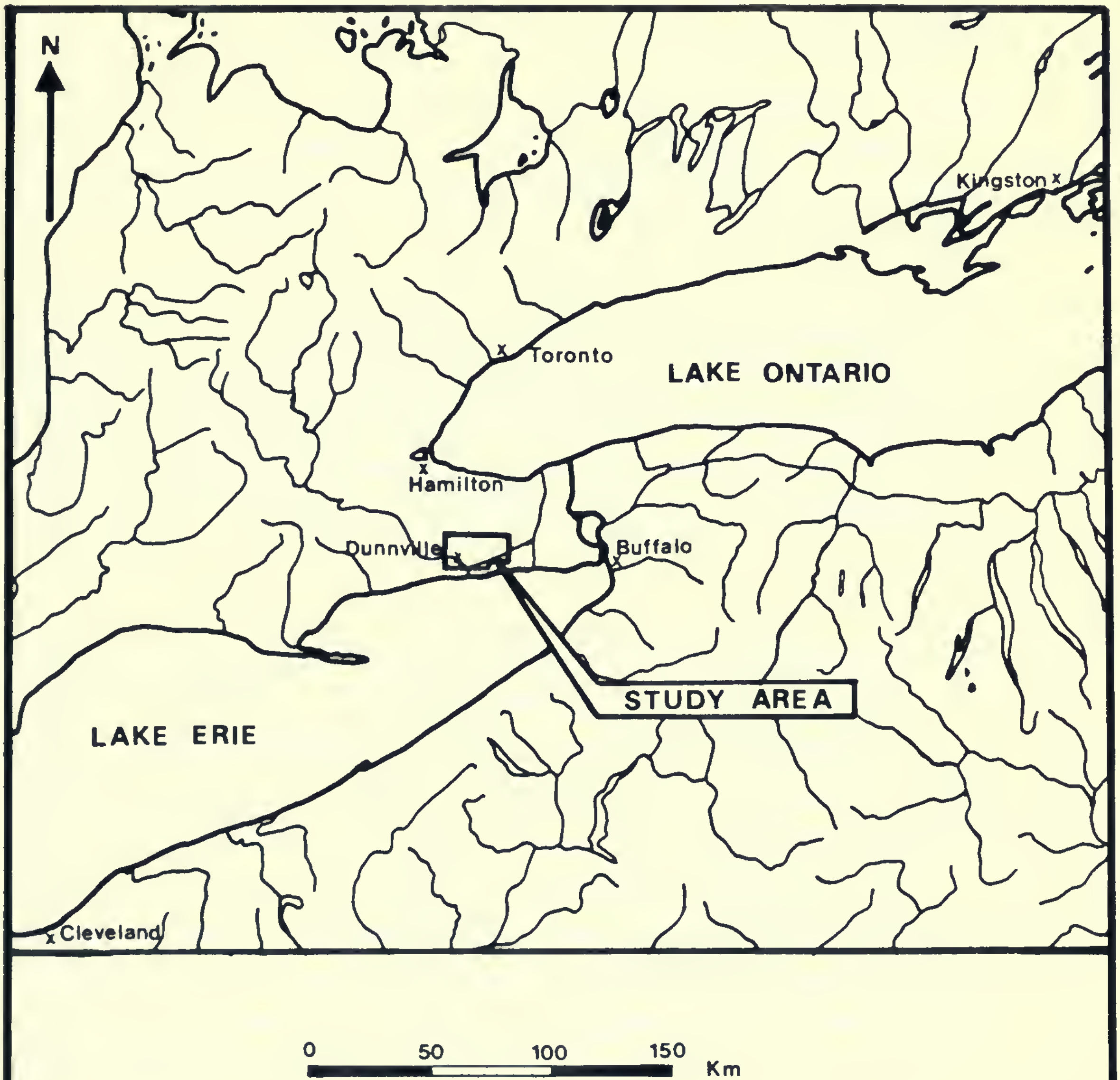


FIGURE 1

LOCATION OF THESIS AREA

may have led to certain subjective mapping interpretations. This is indicated by comparing the western edge of the Welland map area (Enclosure 3) with the eastern edge of the Dunnville map area (Enclosure 4). It can be seen that some deposits were not mapped using identical parameters, resulting in different degrees of detail and poor matching of unit boundaries between the two maps.

Despite the above noted problems, these preliminary maps were considered to be satisfactory as a base for this investigation, because, in this case, detailed outlines of surficial deposits were not necessary for detailed sedimentological examination. This is also the reason why the thesis area was not remapped by the author.

The most recent published work concerning part of the thesis area is that by the Staff of the Engineering and Terrain Geology Section, Ontario Geological Survey (1984). This Aggregate Resources Inventory Paper (ARIP number 67) is an excellent report on the inventory and evaluation of aggregate resources in the Town of Dunnville, and contains much information relevant to the economic aspects of aggregate resources in the Dunnville area. In ARIP 67, much of the technical discussion of Quaternary history and mapping of the area's deposits are again based on Feenstra's works, particuarly Feenstra 1972 and 1974.

Purpose of the Study

The surficial deposits of interest to this study represent a post-glacial deltaic/lacustrine/aeolian system of limited areal extent. The objectives of this study were 1) to gain insight into the sedimentary environments of these sediments during their deposition, by detailed examination of the sedimentology of

selected samples (in particular, the question of the source of the dune sand will be considered; 2) to evaluate the methodology of field and laboratory examination of unconsolidated sediments, including the effect of sampling method on grain size parameters; 3) to attempt to determine the absolute age of the inland aeolian dunes; 4) to document the different sediment and soil types present throughout the thesis area; 5) to explore and establish facies relationships between different sediment units; and 6) to plot the Folk and Ward grain size statistics of samples on ternary graphs, maps and bivariate graphs in an attempt to determine the potential usefulness of these parameters in examining and distinguishing between different surficial deposits, and attempting to clarify their sedimentological relationships.

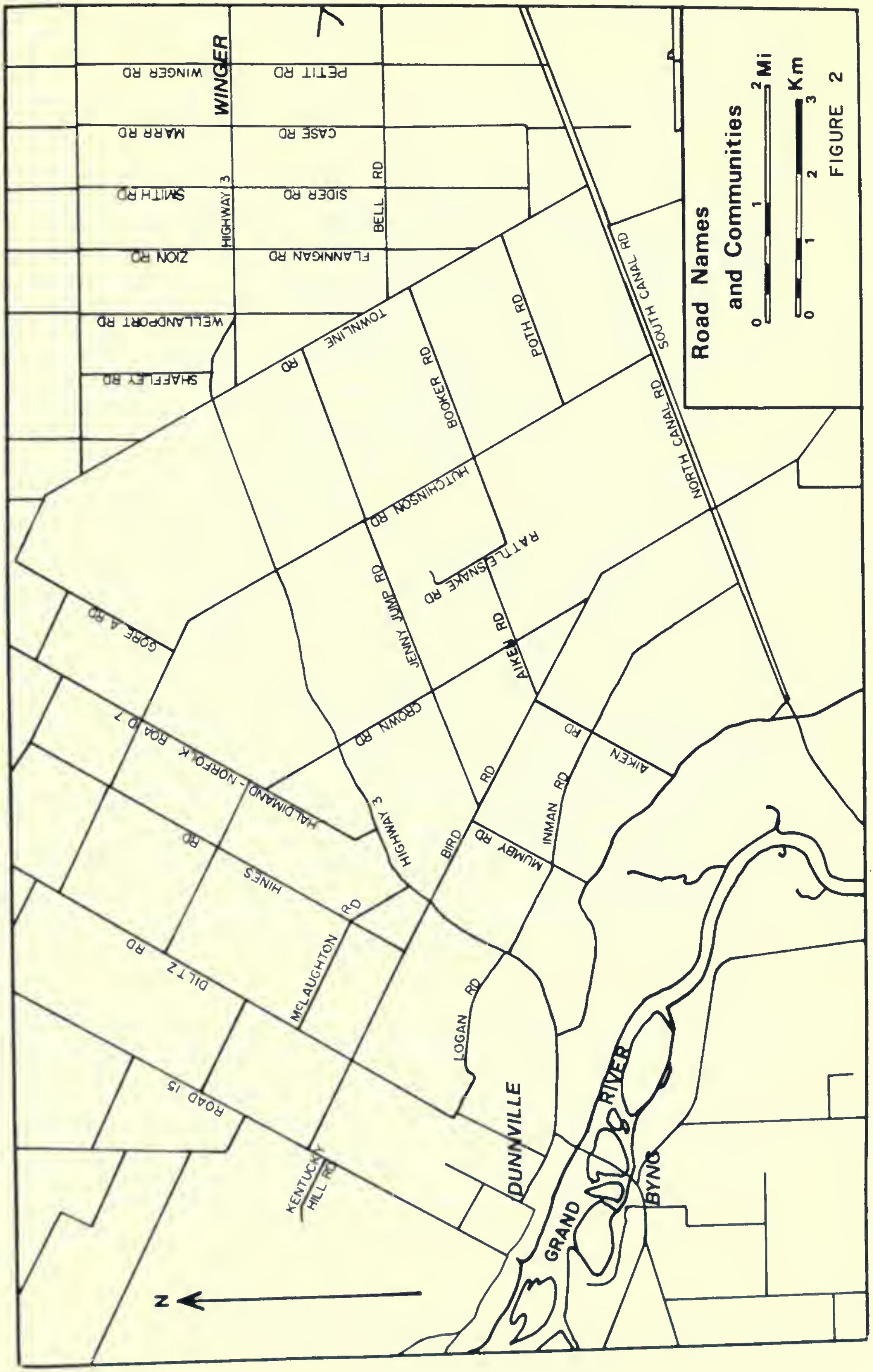
The Study Area and Quaternary History

The sediments which are the main focus of this investigation, lie east and north of Dunnville, in an area approximately 15 kilometres long by 5 kilometres wide. The main access and transportation route for the region is King's Highway #3 (Fig. 2) which runs east-west through the northern part of the area. The study area straddles the boundary between Wainfleet township of Region Niagara to the east, and Moulton township of Haldimand/ Norfolk Region to the west.

Feenstra (1972, 1974, and 1981), studied the Quaternary geology of the area and his correlation of glacial lake stages is used in this thesis, because his (1981) reference is the only one found in which a "Lake Dunnville" stage is recognized. Therefore, the following summary of Quaternary history is based on the descriptions provided by Feenstra in the above references.

Wentworth Till, exposed in drumlins to the northwest of the map area, is the oldest Quaternary deposit of Late Wisconsinan age in the area. In the map area, this till, or its equivalent, was deposited by the Lake Ontario-Erie ice lobe and is present at depth immediately above the bedrock. It consists of a gravelly silt till. The orientation of striae on bedrock and of long axes of drumlins indicates that glacial movement was mainly towards the southwest to west-southwest. (Feenstra, 1972 and 1974).

The next younger unit deposited was the Halton Till, exposed at the surface south of Dunnville, near Lake Erie. This unit was also deposited by the Ontario-Erie glacial lobe, moving in a generally southwesterly direction across the Niagara Peninsula. It consists of a clay to clayey silt till with a hummocky surface. (Feenstra 1972 and 1974) (See grain size analysis, Appendix I).



Road Names and Communities

FIGURE 2

After deposition of the Halton Till, the next younger Quaternary deposit is the glaciolacustrine clay and silt unit, representing deposits of lakes from Lake Whittlesey/Warren I to pre-Lake Dana time. (See Table 1). The first of these lakes to cover the Dunnville area after final deglaciation was glacial Lake Whittlesey/Warren I, with a water depth of approximately 60 metres (inferred from Figure 3). The opening of progressively lower outlets for glacial lakes resulted in successively lower water levels, until the existance of Lake Dunnville with a water depth of approximately 6 meters (Feenstra, 1981 and personal communication, 1982). Lake Dunnville was present approximately 12,400 years BP (Feenstra, 1981 and Terasmae et al, 1972). According to Feenstra (1981), it was during this time that an ancestral Grand River entered the lake(s) and began to deposit the coarse sand delta at Dunnville. The thin apron of fine to very fine-grained sand and silt was also laid down at this time, as a pro-delta deposit over the glaciolacustrine clay and silt. The Lake Dunnville phase, as with all post-Lake Whittlesey lake phases, lasted only one or two centuries before a lower lake level was established by the opening of a lower outlet by glacial retreat. (Dreimanis and Goldthwait, 1973). After Lake Dunnville's level had dropped and the glacio-fluvial deposits were exposed to the air, prevailing westerly winds began blowing the sand into the longitudinal and parabolic dunes seen between Dunnville and Winger. (Feenstra, 1972 and 1974). This period of aeolian reworking is estimated to have occurred between 12,300 and 12,000 years BP, during the Two Creeks Interstadial.

Boreal woodlands, predominantly spruce, followed the retreating glacial ice (and lakes). It is presumed that vegetation associated with these woodlands served to stop the erosion and transport of the sandy material, and to stabilize the dunes. About 10,000 to 11,000 years BP, pine forests began to replace spruce, particularly in better drained areas (Dreimanis and Goldthwait, 1973).

TABLE 1. CORRELATION OF FORMER LAKE STAGES AND "HALTON" ICE MARGINS IN THE NIAGARA PENINSULA. (From Feenstra, 1981)

YEARS BP	LAKE STAGES: ERIE BASIN	LAKE STAGES: ONTARIO BASIN	ICE MARGINS: NIAGARA PENINSULA
12 100*	Early Lake Erie / Lake Tonawanda	Lake Iroquois	Ice margin in Ontario basin retreating further east-and northward away from the Niagara Peninsula
	Early Lake Erie	Proglacial waters ponded between ice margin and Niagara Escarpment	
	Lake Dunnville Lake Dana	Possibly extending for short distances into Ontario basin.	
	Early Lake Algonquin		Ice margin oscillated over short distances between Vinemount Moraine and Lowland north of Niagara Escarpment
	Lake Lundy		
	Lake Grassmere		
	Lake Warren III		
	Lake Wayne		
	Lake Warren II		Niagara Falls Moraine Fort Erie Moraine Crystal Beach Moraine
	Lake Warren I		Wainfleet Moraine Mohawk Bay Moraine
13 000+	Lake Whittlesey		Inferred terminal position Port Huron readvance

*Calkin (1970)
+Calkin (1970); Dreimanis (1966); Lowdon et al. (1976, GSC-2213).

Access

Permission for property access was freely given, except in posted areas, or areas where agricultural activity prohibited entry.

Drainage ditches along roads provided some exposures, as did roadcuts through some of the higher features. Generally, exposures along roads were limited in both number and extent because of the low feature relief. (See Plate 1)

Some excellent exposures were found in small sand pits scattered throughout the thesis area. (See Informal Site Name map, Fig. 4). Excavations were rarely extended below the average elevation of the region, (approximately 178 metres above sea level) because of the poor drainage and high water table present.

Field recognition of the low-amplitude dunes was hampered by both bush vegetation and farming procedures. Cleared land provided an unobstructed view of the ground surface, as seen in air photos, but plowing, harvesting, and attempts at draining some areas has altered surface topography and soil colour enough to produce confusing patterns. Through erosion and cultivation processes, material from topographically "high" points (1-2 meters above the surrounding area) is gradually being moved and deposited towards the edges of the features, thus smearing any boundaries that may be present in the field. Deliberate flattening of the land for cultivation, and removal of material as a source of aggregate had the most serious effect.

A

B

Plate 1: Typical Dunnville Dunes

A: Dune south of Hwy. 3, site of sample PD 414
View is looking north

B: Mumby Road dune

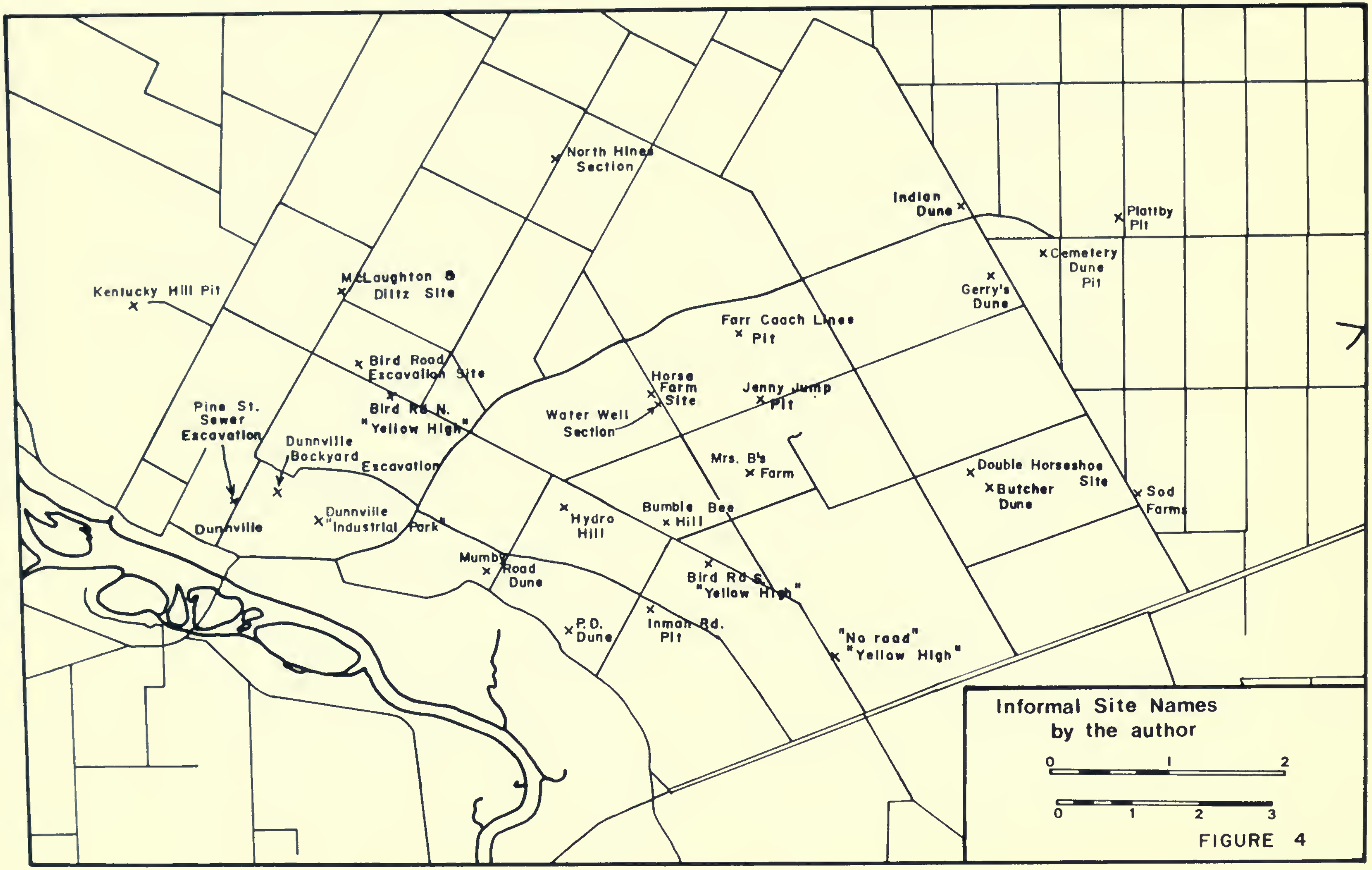

Kentucky Hill Pit
McLaughton & Diltz Site
North Hines Section
Indian Dune
Plattby Pit
Cemetery Dune Pit
Gerry's Dune
Farr Coach Lines Pit
Bird Road Escavation Site
Bird Rd N. "Yellow High"
Pine St. Sewer Escavation
Dunnville Backyard Escavation
Dunnville
Dunnville "Industrial Park"
Horse Farm Site
Water Well Section
Jenny Jump Pit
Mrs. B's Farm
Double Horseshoe Site
Butcher Dune
Sod Farms
Hydro Hill
Bumble Bee Hill
Mumby Road Dune
Bird Rd S. "Yellow High"
Inman Rd. Pit
P.D. Dune
"No road" "Yellow High"
Informal Site Names by the author
0 1 2
0 1 2 3

FIGURE 4

M E T H O D S

INTRODUCTION

It was decided to use grain size analysis to obtain sample parameter values over the whole thesis area (large scale mapping) and over individual exposures of deposits (small scale mapping). Grain size parameters are a convenient way of expressing and keeping track of sedimentological patterns or trends that may be present within a deposit, either at the large or small scale. It is assumed that the sedimentological conditions present at the time of sediment accumulation will be "recorded", to a certain extent, by the grain size distribution of the material sampled. This is not to suggest that grain size distribution provides all the answers to questions about environment of deposition. However, the analysis of sample grain size parameters can give a very good indication of such, and it is one of the goals of this thesis to determine the potential usefulness of grain size parameters in examining and distinguishing between various surficial deposits, and attempting to clarify their sedimentological environments.

The mass of data obtained from grain size analysis was plotted on different maps and graphs in the hope of being able to distinguish between different types of deposits, to attempt to clarify sediment deposition patterns and to model facies relationships between selected depositional units.

This is not to imply that grain size parameters are the only data source used to achieve the above mentioned goals, but they are a very important component in these efforts. The examination of sedimentary structures and, to a certain extent, geomorphology, are also fairly significant factors providing evidence from which a synthesis of data was made.

FIELD METHODS

The examination of airphotos taken over the thesis area in 1978 proved to be a disappointing exercise. At the scale of the photos examined (1:10,000), it was difficult, if not impossible to distinguish between the major types of surficial deposits illustrated by Feenstra (1972 and 1974).

Field observations seemed to indicate that the best ways to differentiate and assign preliminary classifications of depositional environments to samples, were on the basis of 1) grain size, 2) geomorphology and 3) sedimentary structures. Feenstra's preliminary maps (1972 and 1974) were extremely useful as preliminary guides to depositional environments.

It was fairly simple to differentiate material of Feenstra's unit #9 (coarse sand delta at Dunnville) by its grain size, proximity to the west end of the thesis area and the occasional discovery of pebble-size clasts. The presence of this unit directly above massive clay (the glaciolacustrine deposits of Feenstra, 1972 and 1974) was also a good indication of its environment of deposition. Confusion arose, however, when a fine sand with current ripple cross-lamination was found, directly above massive clay (as at the Horse Farm Section, Figure 46). It was not known whether to classify this material as a delta deposit, or a deposit of delta distributary channel infill, or as material of the silty/sand apron. For purposes of record, this particular type of deposit was simply classified as "unknown environment of deposition".

Samples were deemed to be from Feenstra's silty/sand apron (unit #3b, 1972 and #8, 1974) if they were obtained in the eastern portion of the map area; consisted mainly of fine sand and/or silt, and were not on topographic highs.

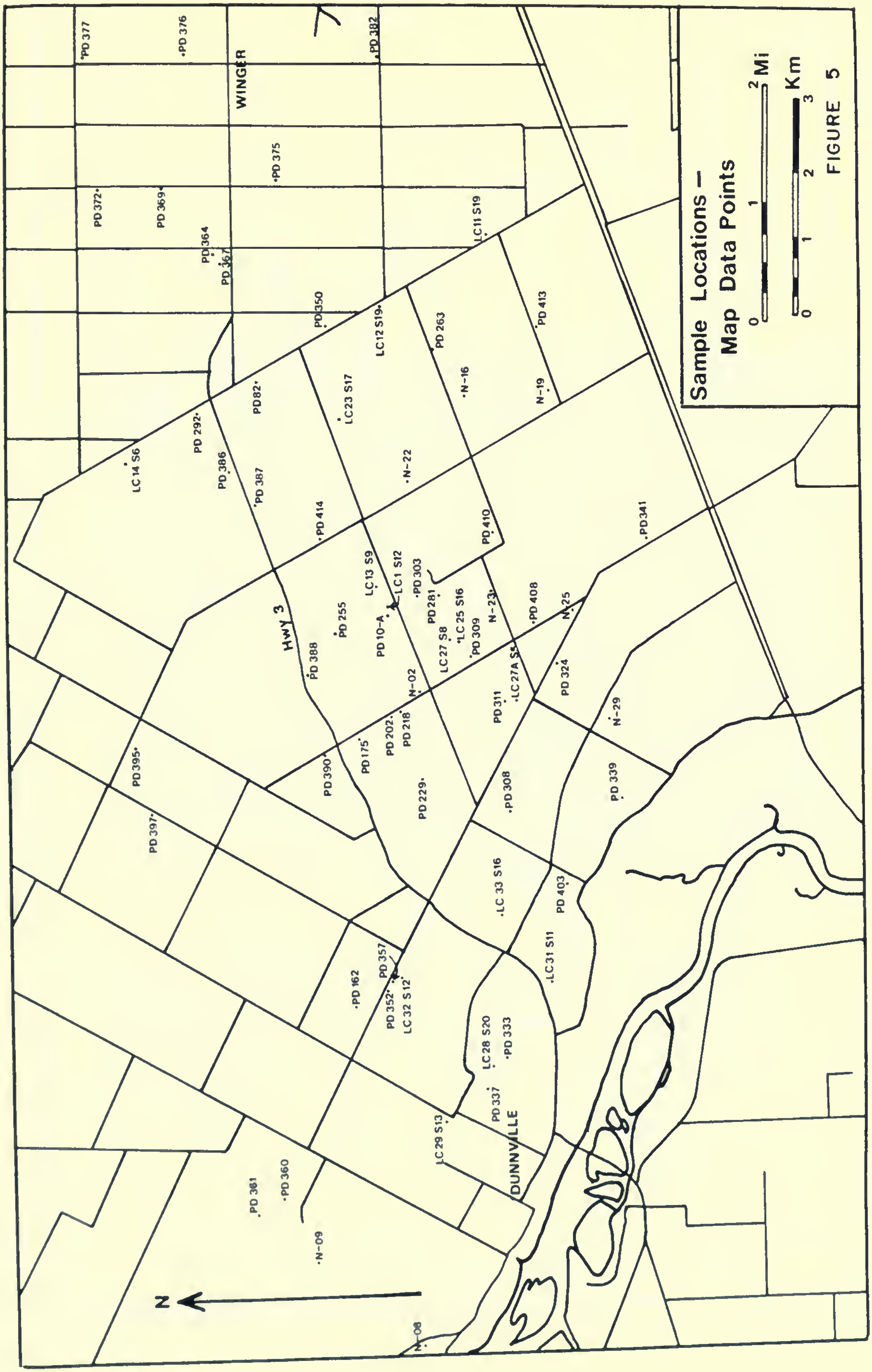
Samples of dune sand (Feenstra's units #3d, 1972 and #10, 1974) were easily identifiable by virtue of their locations on topographically high spots, and their relatively coarser grain size when compared to surrounding sediments. Because the dune sands were relatively well exposed and formed the most interesting deposit in the area, they were sampled in more detail than other units. This resulted in an abundance of samples of dune origin to be analyzed.

Differentiation of samples from the Wentworth and Halton tills, as well as stream terrace samples, were based on locations selected from Feenstra's (1974) map.

Samples were collected in the field with the objective of examining surficial materials over the entire study area. The sample location maps (Figs. 5 and 6, Enclosure 2) show the distribution of data points, as well as the generally east-west and north-south lines of coring sites.

Surface samples were collected by: 1) vertical channel sampling; 2) random spot sampling; or 3) systematic spot sampling over a vertical interval. A description of sampling techniques is detailed in Appendix IV.

There are many small-scale sand pits scattered throughout the thesis area (Fig. 4). The size of the sand pits varied from a few tens of cubic meters removed from the side of a hill, for the personal use of the landowner (ie. at P.D. Dune), to extensive excavation for various purposes, including road building (ie. Kentucky Hill, Butcher dune). The sand pits provided an excellent opportunity to examine exposures of dune material (Plates 2 and 3). Certain pits were selected for detailed examination. Channel samples, spot samples and individual laminae samples were all obtained from a single exposure in the Cemetery Dune pit to evaluate the effect of choice of sampling method on sample parameters.



Sample Locations — Map Data Points

FIGURE 5

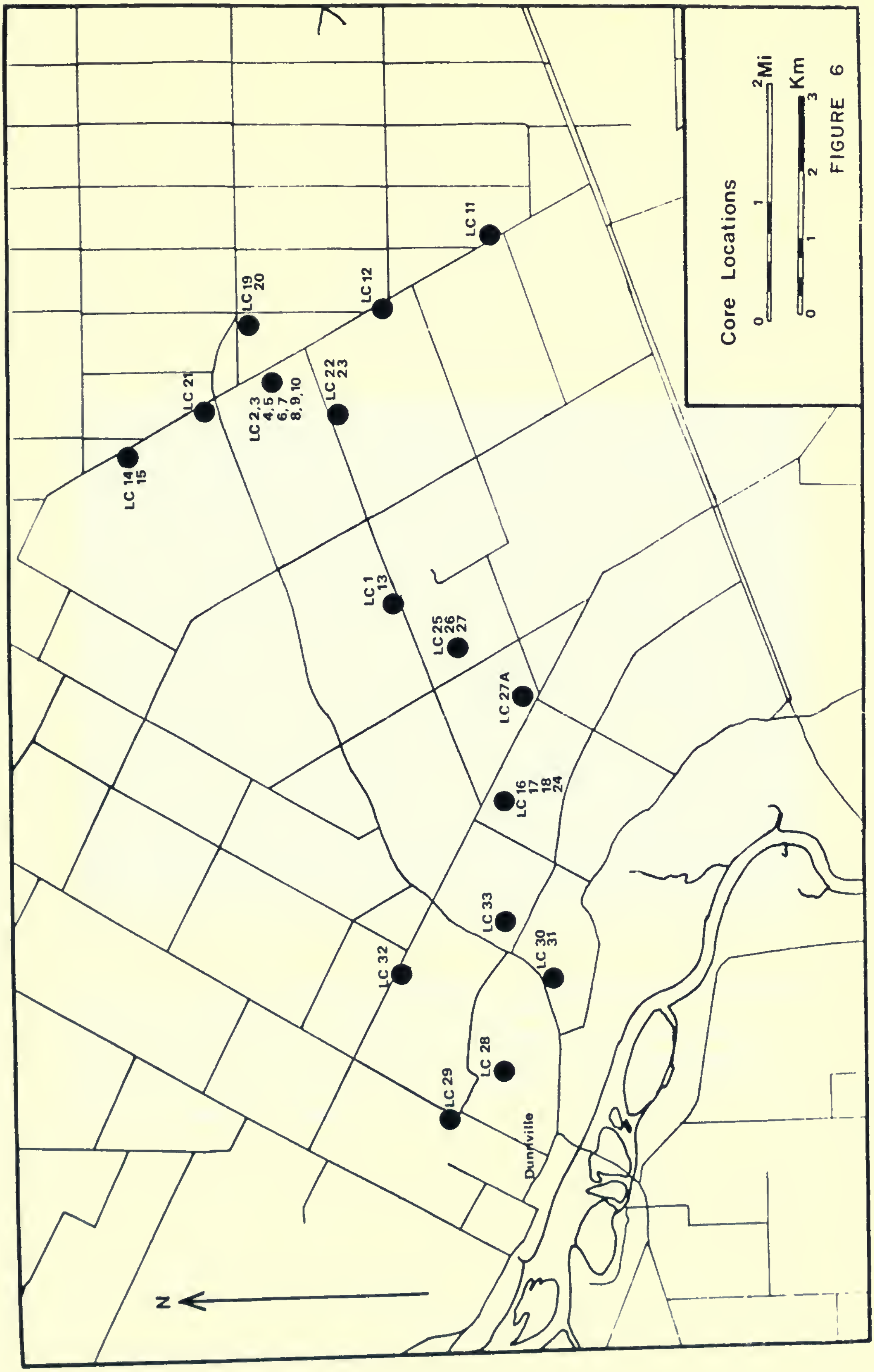

Core Locations
0
1
2 Mi
0
1
2
3 Km
LC 11
LC 12
LC 19
20
LC 21
LC 2,3
4,5
6,7
8,9,10
LC 22
23
LC 14
15
LC 1
13
LC 25
26
27
LC 27A
LC 16
17
18
24
LC 33
LC 30
31
LC 32
LC 28
LC 29
Dunnville
N

FIGURE 6

Plate 2: Dune Excavation Showing Root Casts (Jenny Jump Pit)
Root casts are dark centred white blebs.
Note variety of grain sizes in exposure, also some graded bedding and distorted bedding. Exposure is approximately along strike of bedding plane. Dip of beds in upper part of photo is towards viewer.

Plate 3: Dune Excavation Showing Excellent Exposure of Dune Material.
(Jenny Jump Pit - west wall)

The coring program was time-consuming both in the field and in the lab. Coring was necessary in order to obtain samples from locations where a hand-dug pit was not feasible, for example, in low-lying areas where sediments were saturated with water. Cores were also taken whenever a permanent example of in-situ sediment relationships was required. The coring equipment and method used were patterned after those employed by Dalrymple in coring tidal sediments in Cobequid Bay, Nova Scotia (Dalrymple, personal communication, 1983). The method consists of pounding a plastic sampling tube into the ground, sealing the protruding end of the tube, and extracting the tube from the ground. For a detailed description of the coring technique, see Appendix IV. Despite many difficulties, good cores up to 1.6 metres in length were obtained from most sites with little or no disturbance of the sediments. Results can be seen by examining the Core Descriptions, core peel photographs and X-radiographs. (Enclosure 1 and Plates 5 to 11.)

Cores were procured from dunes in a general east-west and north-south pattern (Fig. 6) to determine trends of grain size or sedimentation pattern over the thesis area. Intensive coring was employed over a single dune, to assist in the examination and interpretation of sediments over a localized area. The selected dune displayed a good crescentic form, was relatively undisturbed by agricultural activities, and was easily accessible. This dune was located 0.7 km south of Hwy. 3 and immediately west of Townline Rd. (For convenience, this site was referred to as "Gerry's Dune".) (Fig. 4, Plate 4.) The dune was also trenched by backhoe at a right angle to the strike of the slipface for a length of 11 metres, and then parallel to the crest of the slipface for a length of 4.5 metres.

Many different methods were investigated for the making of peels of unconsolidated sediments to enhance and preserve the structures within. The variety of grain sizes and moisture conditions encountered in pits and trenches necessitated a compound suited to many different surfaces. Epoxy resins were considered, but were rejected, due to exorbitant cost. Other materials such as spray

adhesive, plastic casting resin, an alternative epoxy resin, paraffin wax, epoxy floor sealant and fiberglass resins were experimented with, usually producing disappointing results due to the fine grain size and damp nature of some exposures. Plain white glue, specifically Le Pages' Bondfast, proved to be the preferred substance for making peels.

When diluted, two parts water to one part glue, then brushed or sprayed on the sediment surface, this mixture achieved sufficient differential penetration in both wet and dry sediments to produce a detailed record of internal structures. A significant disadvantage of this material is the length of time usually required for sufficient hardening to facilitate transport back to the laboratory. The major advantages are its availability, versatility, ease of handling, and low cost. Because it is water soluble, its penetration into water-saturated sediments is good, resulting in a 3-dimensional expression of internal structures. The largest peel obtained with this method measured 55 cm by 80 cm (Peel PD#5, see Plate 18) and clearly indicates detailed bedding. White glue was also extensively employed when obtaining peels of cored material to be photographed and X-rayed. A description of this method, as applied to cores, appears in Appendix IV.

A

B

Plate 4: Gerry's Dune Slipface and Trenching

A: Slipface approximately 2 metres high. View is from trench location, looking southwest.
B: View of trench looking down slipface.

LABORATORY METHODS

Physical Analysis of Samples

Over 1,100 individual samples were obtained for this investigation, including over 680 subsamples from cores. In the interest of time, it was necessary to choose representative samples for detailed analysis and mapping purposes. One hundred and eighty-two different samples were analyzed for grain size parameters. Some sets of samples were obtained from the same exposure or core in order to study sampling method effects. To facilitate mapping, one sample from each exposure or core was selected as representative. In addition, resieving and accuracy repeats added 35 to the number of analysis runs. (Appendix III)

All samples were air-dried at room temperature in their original sample bags before commencing grain-size analysis. The sample was then gently crushed with a wooden rolling pin.

Folk's (1974) sieving method was followed with the modification of adding the 100-gram subsample to 50 ml of dispersent solution (0.5% sodium hexametaphosphate) and placing the mixture in an ultrasonic bath for 15 minutes. This produced a muddy slurry of disaggregated particles that was wet-sieved using a 4.0 phi sieve on a Fritsch Analysette vibrating sieving machine. All the muddy water passing through this sieve was retained for analysis of fines. The volume of the liquid was reduced to approximately 50 ml by centrifuging and decanting. This was the suspension used for SediGraph analysis.

After wet-sieving, the material retained on the 4.0 phi sieve was dried at 50°C, weighed, and sieved at 1/2 phi intervals using standard sieving techniques. The weight of material retained on each sieve was determined to three decimal places.

Because of the large number of analyses required, the Micromeretics® SediGraph 5000D Particle Size Analyzer was utilized for the analysis of fines. Using the SediGraph machine, approximately 20 minutes per sample were needed to obtain particle size data over the 4.0 phi to 10.0 phi range. (Appendix IV)

Some samples were particularly rich in fines, making the slurry for SediGraph analysis much too concentrated. If it was necessary for the slurry to be diluted by adding more than 400 ml of dilute dispersant solution, it was deemed necessary to freeze-dry the entire suspension and split the resulting dry sediment to obtain a working sample weighing between 5 and 10 grams. This working sample was rehydrated and run through the SediGraph with much improved results.

Comparison of analyses of fresh and freeze-dried portions of the same sample generally indicate no significant effect of freeze-drying on grain size parameters (Appendix II). In his paper on time and method dependent size distributions of fine-grained sediments, Nelsen (1983) obtained a similar conclusion.

A total of 100 samples were chosen for examination of heavy and light mineral fractions in order to gain some insight as to the nature of mineralogical maturity. The 3.0 to 3.5 phi fraction of sieved material was selected for heavy mineral separation. This interval was selected because it contained a visible concentration of heavy minerals, was close to or overlapped intervals used by other workers for heavy mineral studies, and was slightly finer than the median grain-size of quartz in the sample. Minerals with higher specific gravities tend to have a median of 0.5 to 1.0 phi size smaller than the median size of quartz in the sample.

The separation of heavy and light minerals was achieved by using the heavy liquid bromoform (S.G. 2.90 g/cc^3) and an overflow centrifuge like that described by Ijlst (1973). The method was quick, fairly simple, and resulted in good, clean separations. Both the heavy and light fractions were mounted on slides using a thin film of white glue, and gross observations of mineralogy were

Several small (15x15x30 cm) "box cores" were taken in the field to attempt a microscopic examination of structure. The box cores were obtained by tapping an open-ended metal can vertically into a sandy deposit, noting the orientation of the can with respect to north and vertical, and digging the can out. Problems arose when it was attempted to open the cans, as vibrations from sawing tended to destroy the internal structure of the sand. It was decided to try to impregnate the unconsolidated material before removal from the metal can. Liquids, such as epoxy resins, white glue, paraffin wax and fiberglass resins, were tried, under both normal pressure and vacuum. None produced entirely satisfactory results, but a few blocks of artifically-cemented sand were obtained, using the white glue as a cementing agent. Epoxy resin was moderately successful in impregnating small (2x4 cm) unoriented blocks of sand, but the fine-grained nature of the material prevented the resin from penetrating deeply. A few thin sections were obtained, despite the problems encountered.

Samples selected for XRF analysis were chosen in the hope of reflecting chemical or mineralogical differences between the different sedimentary units of the area. Some samples were chosen specifically to investigate soil processes.

The samples were oven-dried at 105°C overnight and then crushed and ground to less than 3.75 phi (200 mesh) using a roller mill if necessary, and a tungsten carbide shatter box. The loss on ignition (L.O.I.) was calculated for each sample and fused glass discs were prepared for major element analysis. The glass discs were prepared by mixing one gram of sample with 10 grams of X-ray Fusion Flux (Chemplex), plus the L.O.I. weight in additional Fusion Flux. This was heated at 1100°C for 30 minutes and poured

into a platinum mold. X-ray Fusion Flux is composed of 90% lithium tetraborate and 10% lithium carbonate. Powder packs for trace element analysis were prepared by mixing 7.5 grams of sample with one gram of binding agent (X-ray Mix Tablets - Chemplex). This mixture was pressed in a hydraulic press for 20 seconds at 20 T/cm^2.

A Phillips PW 1450 Sequential Automatic X-ray Spectrometer was used for major and trace element analysis. Standards from both the United States Geological Survey and Centre de Recherches Pétrographiques et Géochimiques were used as references. Samples whose analyses of total major element oxides plus L.O.I. totalled less than 97.5%, or greater than 102.5%, were rejected. These samples are indicated by an asterisk (*) in Appendix IX.

Core peel photographs were obtained by using a Hasselblad camera with a 2 1/4 inch (5.715 cm) format. This produced a fairly large negative for recording detail. The film used was Kodak VPS 120 colour film with an ASA rating of 160. The finished print was exposed on Sakuracolor paper. The X-ray unit used for the X-radiography was a Philips K200 (200 kV, 5mA) type number 942107102022. Exposures were done using 100m kV, 3mA for 3 minutes. Agfa-Gaevert X-ray film was used, and prints were produced on Sakuracolor paper.

The core peels were repositioned between the time of X-ray exposure and time of photography, therefore corresponding groups of images (face-to-face sets) may not be perfectly aligned. The length of the majority of core peels demanded photographing sets of upper and lower halves and reproducing them on consecutive pages in this thesis.

Calculation of Grain Size Parameters:

Grain-size statistics used in this thesis are those of Folk and Ward (1957). They were derived from either computer analysis of percentiles, or manual calculations utilizing graphic analysis. (Appendices VII and VIII). The parameters calculated include:

$$\text{Mean Size } (M_Z) = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

$$\text{Median Size} = \phi 50$$

Sorting (Inclusive Graphic Standard Deviation):

$$(\sigma_I) = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

Skewness (Inclusive Graphic Skewness):

$$(Sk_I) = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

Kurtosis (Graphic Kurtosis):

$$(K_G) = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$$

It should be noted that the Normalized Kurtosis ($K_G{}^1$) mentioned by Folk and Ward (1957) has not been used in this thesis. Also, Folk and Ward recommended the abandonment of the Median as a measure of average size. Their reasoning was that it was a misleading measure since it was based on only one point of the cumulative curve.

In general, calculation of grain-size statistics was accomplished by utilizing an HP 3000 or HP 1000 computer, with a grain-size analysis program developed by Dalrymple and Knight and modified by the Petro-Canada Research and Development group (Knight, personal communication, 1984). The program enabled calculation of total weights of fractions, grain-size parameters using several different methods, and a graphic illustration of grain-size distribution (Appendix VII). Folk and Ward statistics were used for mapping and graphing purposes.

Several samples would not run to completion on this computer program. These samples contained distributions that were too open-ended either at the coarse or the fine end. Also, the program appeared unable to accept samples with data input coarser than -1.0 phi. The samples that would not run on the computer had to be calculated manually. In order to facilitate this, the author developed a Grain-Size Analysis Manual Worksheet in order to obtain, for each sample, a cumulative frequency distribution to be plotted on probability graph paper (Appendix VIII). Once a frequency curve was generated, the phi values at 5, 16, 25, 50, 75, 84 and 95 cumulative percent were read off the curve and used to calculate the sample median, mean, sorting, skewness and kurtosis (Appendix VI).

DATING METHODS

Quaternary stratigraphy has been the most useful method for determining the relative ages of the dune deposits in the thesis area. A more difficult date assignment is the time of the cessation of aeolian action, represented by the stabilization of the sand materials by vegetation.

From the time of lake recession and emergence of sediment, one can only estimate how long it would take to grow sufficient vegetation to stabilize wind-blown sand. Flint (1971) states the following:

"During deglaciation....vegetation lost little time in repopulating areas of bare drift. Modern analogies exist. In post-glacial time, on the moist coast of southern Alaska, bare drift has been covered with a succession of plants ending in mature forests of large spruce, all within a lapse of no more than 200 years. Despite the fact that, in that oceanic climate, conditions are exceptionally favorable for plant growth, this figure is impressive".

It is reasonable to postulate then, that vegetation repopulating the area of the ancestral Grand River deltaic plain would be sufficiently abundant to decelerate or halt the transportation of granular materials approximately 100 to 200 years after the deposits were exposed to the air.

A search was conducted in the thesis area for organic material buried by the deposition of sediments. Such material could then be dated by the carbon-14 method (Melville, 1972) to achieve an absolute date for sediment deposition. The search yielded only one example that was suitable for this dating method.

Small (5 mm long) gastropod shells were occasionally encountered during sample examination (ie. samples PD 22, LC29 S1 and LC 19 S3). In addition, sample LC7 S5 contained a pelecypod shell at depth (44 cm.). Of these samples, the shell from PD 22 (Grand River terrace deposit) appears to have been in-situ. The shell was not discovered until the sample was dried and sieved.

The specimens from LC29 S1 and LC19 S3 also appear to be in-situ, but of modern age, since both cores were taken in wet, swampy areas which is a favorable habitat for fresh-water snails. Both shells were also found at less than 15 cm depth.

The pelecypod from sample LC7 S5 is somewhat more perplexing as to its origin. Although the core was taken in a swampy area, the fact that the specimen was found at approximately 44 cm depth points to either a deeply-burrowing creature, or burial at some time in the past. The possibility of accidental burial by man is eliminated, since sediment above the shell showed a steadily-increasing organic content as one moves toward the top surface of the core. This smooth transition from organic-poor at depth to organic-rich at the surface, indicates that the sediments are apparently undisturbed. As with the specimen from sample PD 22, age and paleoenvironment determinations from a single specimen carry high risk, so no definite conclusions can be made with regards to this specimen, except that the environment in the immediate area of the coring station had been wet enough to support pelecypod(s) in the past.

The method of thermoluminescence (TL) dating was briefly considered as a way of dating the age of formation of the delta and dune sediments in the Dunnville area, but rejected because there are many methodology problems associated with TL, equipment is not presently available, and Dreimanis et al (1978) and Dreimanis (personal communication, 1981) state that the dating of geological samples by the TL method is still more a relative than an absolute dating method. Therefore, it is improbable that TL

would be sufficiently accurate for dating the history of the dune and delta sediments east of Dunnville.

With regard to attempting to date the area's sediments by use of paleosols, what appears to be a "B" horizon at depth can be seen on some of the Core Descriptions and core peel photographs; for example: LC4, LC5, LC9 and LC27. It is suspected that these may represent artifically-buried soil horizons, as they seem to occur very close to areas of intense human activity. These should not be confused with true paleosols, none of which were found in the thesis area.

R E S U L T S

GENERAL RESULTS

The methods described in the previous chapter were utilized to obtain the results described here.

Air Photographs:

Examination of airphotos provided the following observations. The difference in drainage patterns and overall "mottling" of soil patterns seems to provide some clues to the identification of areas that are covered by the silty/sand apron and adjacent areas of lake bottom sediments (Feenstra's "glaciolacustrine clay and silt"). The coarser sand delta at Dunnville is obscured by urban development, so patterns in that area cannot be easily distinguished. The low-amplitude dunes on the silty/sand apron rarely manifest themselves in recognizable shapes on airphotos. Large areas of bush land obscure direct observation of the ground surface, such that no dunes can be seen on air photos even where large, well-formed dunes are known to be present from field work.

In cleared areas, a patchy, light-coloured pattern is sometimes present, and these light patches are usually found to be areas of slightly higher elevation in the field. Occasionally, these light patches will have a parabolic shape, open to the west. These are found to outline the site of a dune or the site of a dune that has been planed off, either for agricultural or aggregate use. The agricultural activities of the farmers in the area regularly "scalp" the higher topographic spots throughout the thesis area. The different levels of weathering in the soil are then exposed, producing the light/dark mottled pattern seen on airphotos. As well as unintentionally emphasizing the topographically high spots, the agricultural activities tend to "smear" the boundaries of these spots by gradually moving soil around.

Stereoscopic viewing of the airphotos resulted in the spotting of some of the highest, previously known features, (such as Hydro Hill and Cemetery Dune) but for the most part, this method only revealed an irregular, very gently rolling, non-descript topography.

Age Dating of Deposits

From literature references (Feenstra, 1981 and Terasmae, et al 1972), it can be inferred that the period of deltaic sedimentation in the Dunnville area took place circa 12,400 years BP. After the draining of Lake Dunnville, prevailing westerly winds formed the aeolian sand dunes. From information concerning the establishment of vegetation in a post-glacial terrain (Flint, 1971), the period of active aeolian reworking is inferred to be from 12,300 to 12,100 years BP. Attempts to determine more definite dates of deposition involved a search for materials datable by the carbon-14 method.

Carbon-14

In core LC32, between 36 to 48 cm from the surface, a sandy organic muck was encountered. (See Core Descriptions, Enclosure 1 and Plate 11C). Unfortunately, the shallow depth of this organic material, coupled with its proximity to a major drainage ditch (approximately 7 m away), seems to indicate that the organic material in question was buried by the actions of man, probably by material scooped out of the ditch during its construction and/or subsequent maintenance. Therefore, this material was not seriously considered for carbon-14 analysis.

The field notes of P.J. Barnett, one of Feenstra's field assistants, indicate the possibility of finding an organic deposit in the town of Dunnville (J. Fraser, Ontario Ministry of Natural Resources, personal communication, 1980 and 1981). During the summer of 1973, at a house excavation site on the north edge of town, a peaty muck was found by Barnett.

This sample site (D-354 in Barnett's notes) also contained some shell fragments. The peaty muck occurs at a depth of 45 to 75 centimetres, is irregular in thickness, and is interpreted as a pond or bog deposit by Barnett. The shells were found in a grey silty fine sand one metre below the ground surface. Unfortunately, the only reference to these organic deposits was found in the original field notes, and it is not known if it was attempted to date them by carbon-14 methods.

An attempt was made to duplicate Barnett's discovery of organic material at depth in the town of Dunnville. Unfortunately, no exposed excavations were available in the immediate area at the time of field work for this thesis, but a recently-completed house on Jarett Place (approximately 450 m NE of Barnett's D-354 location) afforded an opportunity to inspect the material removed to form the basement. Although this material was not in-situ, it was examined in the hope of finding organic remains from beneath the surface. No shells were found, but a block of black, peaty sand was recovered from the excavated material, and dated by the carbon-14 method at the radiocarbon laboratory, Brock University (Appendix V). This material yielded an age of 225 ± 100 years BP (BGS 795).

The possibility of dating the chalky, carbonate root casts found within the dune deposits (Plate 2) was considered, but rejected on the grounds of the following. The extremely porous nature of the material makes it particularly susceptible to contamination by modern calcium carbonate from ground water. The samples usually incorporated surrounding sand grains, some of which are sand-sized carbonate rock particles, probably the original source of calcium carbonate for the chemically precipitated root casts. This carbonate sand contamination would be almost impossible to completely remove from the sample, and if present when the CO_2 of the sample was released by HCl for age dating, would introduce an error related to the "infinitely old" carbon contained in the carbonate sand.

In addition to the chemical considerations of dating the root casts, it is extremely doubtful if useful dates could be obtained, since the formation of the root casts would most likely not be related to the deposition of the dune materials in any way.

Gerry's Dune

Observations of the 9 cores (LC2 to LC10) obtained from Gerry's Dune have indicated that over a small, low amplitude dune, sediment characteristics (grain size parameters, internal structures, etc.) can be locally variable. A complete examination of the trench walls showed the exposed sand was nearly homogeneous in texture, but core descriptions and photographs indicate several different sediment textures can be present over the area of the dune. Many difficulties were associated with trenching this dune, including flooding of the lower end of the trench and limited use of the backhoe. Therefore, it was decided that further trenching would not be worthwhile.

Early Diagenesis

Soil processes were examined in order to investigate some grain size and chemical aspects of the early diagenesis of dune sand. For this purpose, samples PD 7A, B, C and PD 16, 17, and 18 were analyzed with an XRF spectrometer (Appendices I and IX).

It is known (Webber and Hoffman, no date) that weathering of soil parent material alters proportions of iron (by leaching and redepositing), aluminum (alteration of feldspars to clays and the translocation of the clay particles) and carbonates (by leaching and redeposition).

Results of the XRF analyses show that, in a general comparison among the major oxides analyzed, proceeding from "parent" light-coloured material to "weathered" red coloured material, the following oxide weight percents appear to increase: SiO_2, Al_2O_3, TFe_2O_3 and Na_2O; the MgO and CaO decrease; TiO_2, MnO and P_2O_5 stay essentially the same; and conflicting results appear with regard to K_2O and L.O.I. The most obvious changes between parent and weathered material occur in SiO_2, CaO and L.O.I analyses.

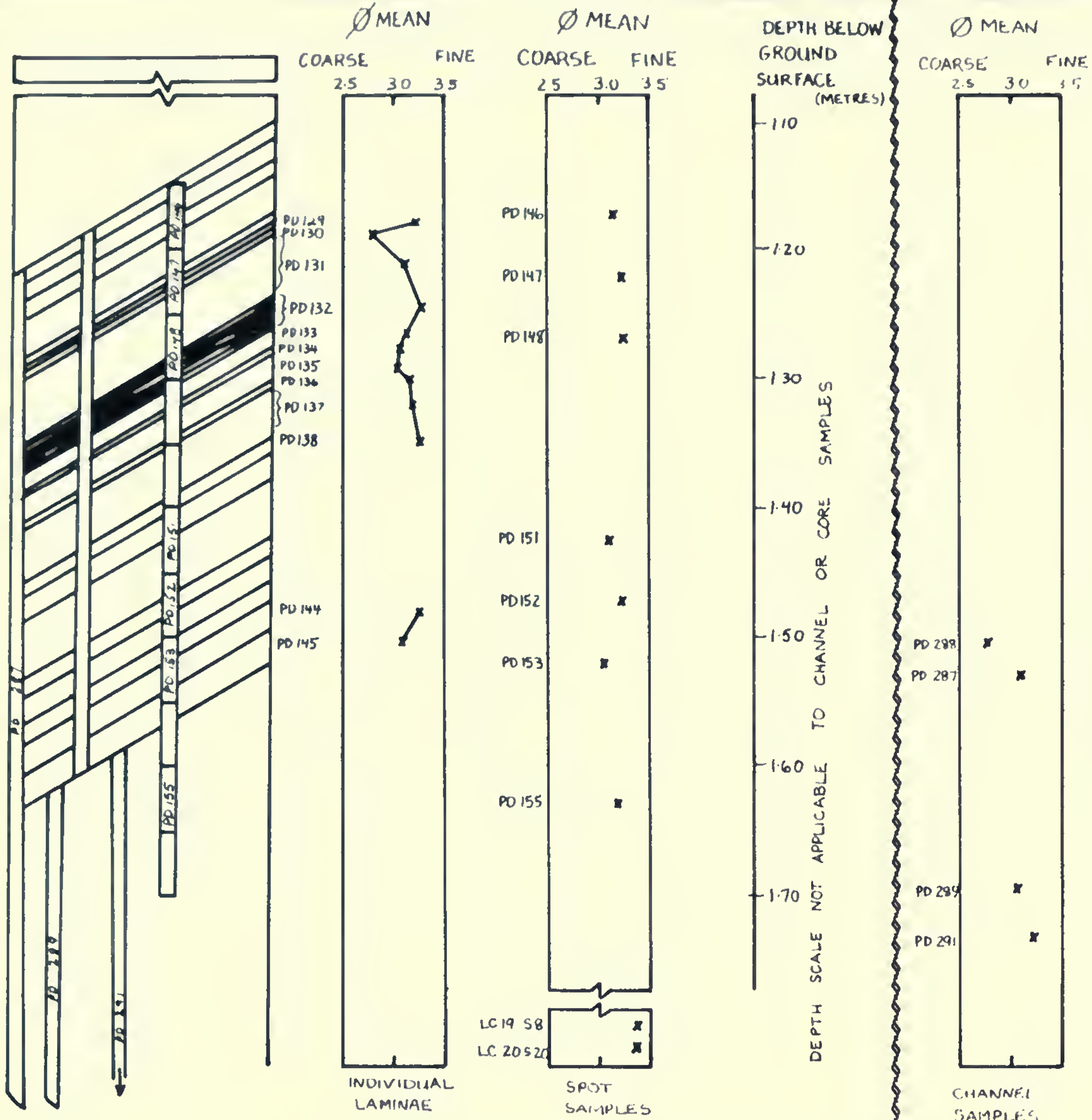
Sampling Effects:

Figures 7 to 11 illustrate the changes in grain size parameters that can take place over a vertical interval, and also demonstrate how different sampling methods result in different data for the same interval.

Mineralogy of the Sand

The mineralogy of the sediment will vary, depending on which size fraction is examined. Observations recorded here are for whole sample averages, unless otherwise noted. The dune sand is dominantly composed (70 to 80%) of angular to well-rounded quartz grains. Carbonate rock particles are the next most abundant component, making up 20 to 30% of the sediment. Minor constituents include metamorphic rock particles, magnetite, feldspar, and gypsum grains. Trace minerals include garnets, amphiboles (mostly hornblende), undifferentiated opaque heavy minerals, micas, epidote and pyroxenes.

The quartz is predominantly monocrystalline, but polycrystalline grains and chert particles are not uncommon. Some very well rounded quartz grains are present, and these usually have a frosted surface texture. Although such frosting is often associated with aeolian sediments, its rarity here indicates that this feature is certainly not characteristic, or even indicative, of the depositional process of these sediments.
The examination of thin sections reveals that there is a definite grain size segregation between individual laminae 2 to 10 mm thick. Good sorting and porosity are evident in some micro-laminae, particularly the coarse layers. Some of these layers suggest slight orientation of particle long axes, sub-parallel to bedding.



ALSO REFER TO FIGURE 56

COARSEST : PD 130 (2.79Ø)
FINEST : LC 19 S8 (3.38Ø)

COMMENTS :

- INDIVIDUAL LAMINAE GOOD FOR SHOWING BED GRAINSIZE EXTREMES
- SPOT SAMPLES APPROACH THE MEAN GRAIN SIZE FOR THE EXPOSURE, AND MAY SHOW GENERAL TRENDS
- CHANNEL SAMPLES SHOW VERY GENERAL TRENDS, BUT SAMPLING ACROSS A SUBUNIT BOUNDARY CAN LEAD TO MISINTERPRETATION OF RESULTS.

FIGURE 7
CEMETERY DUNE
SAMPLING EFFECT
COMPARISONS :
MEAN

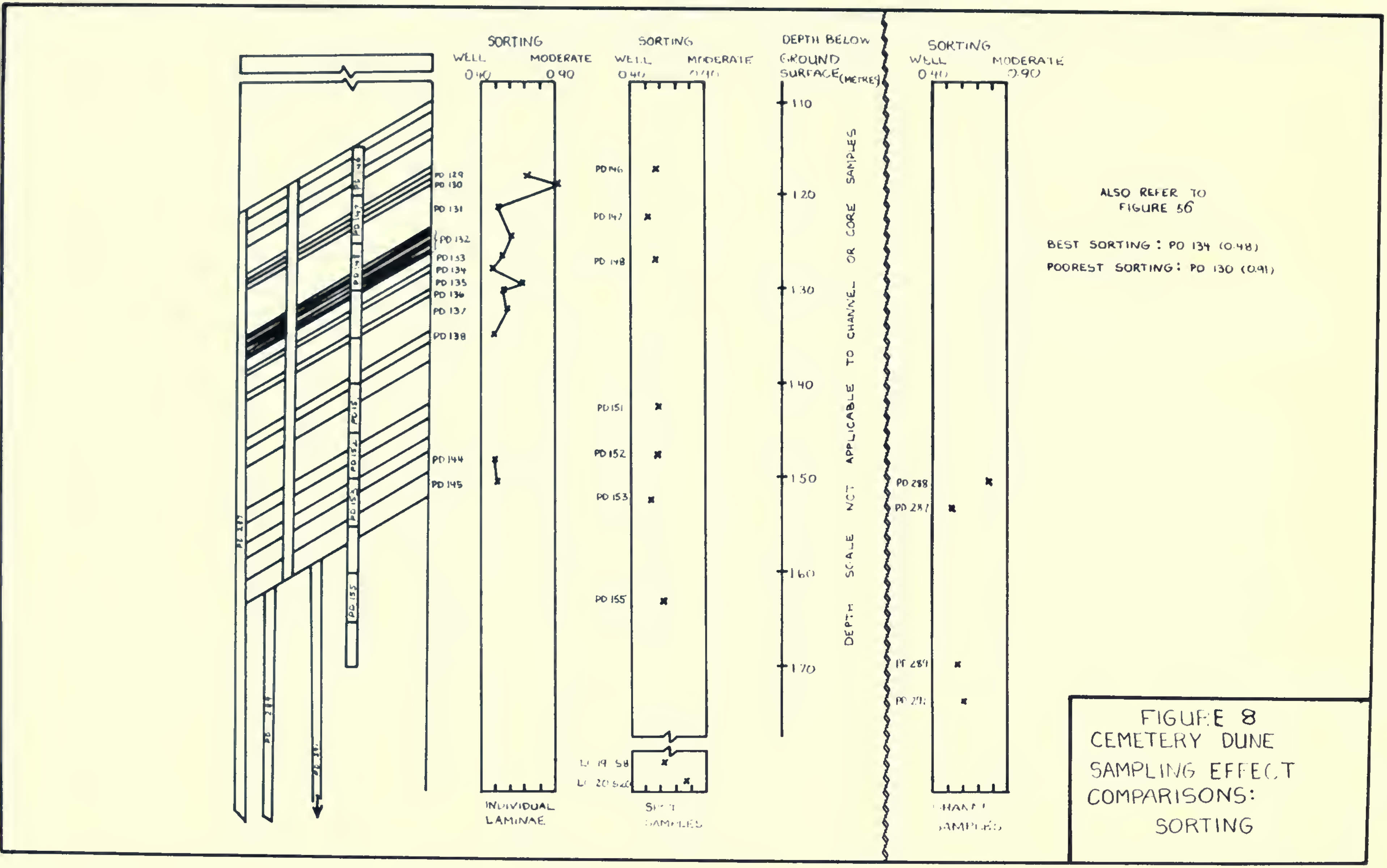


FIGURE 8
CEMETERY DUNE
SAMPLING EFFECT
COMPARISONS:
SORTING

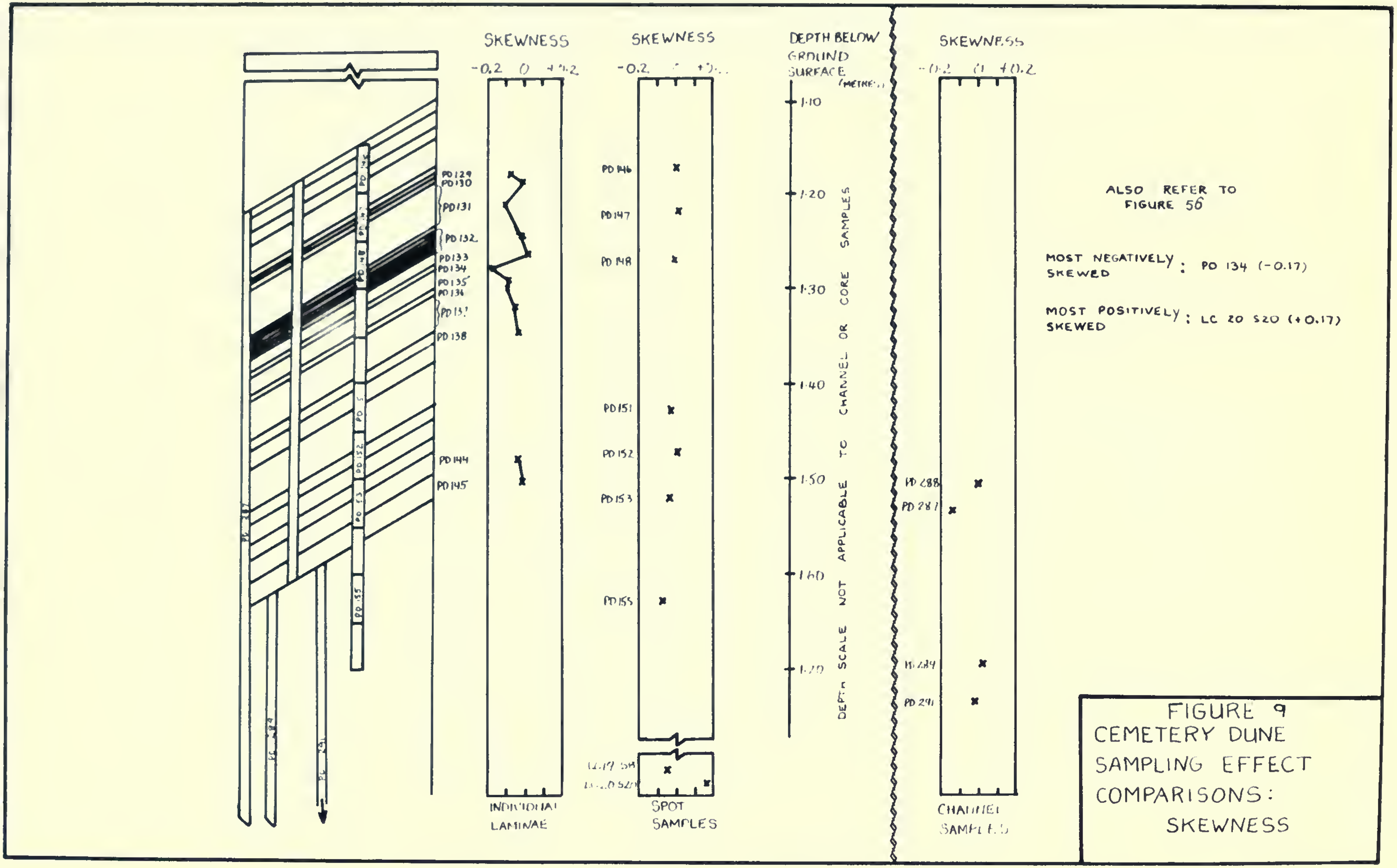


FIGURE 9
CEMETERY DUNE
SAMPLING EFFECT
COMPARISONS:
SKEWNESS

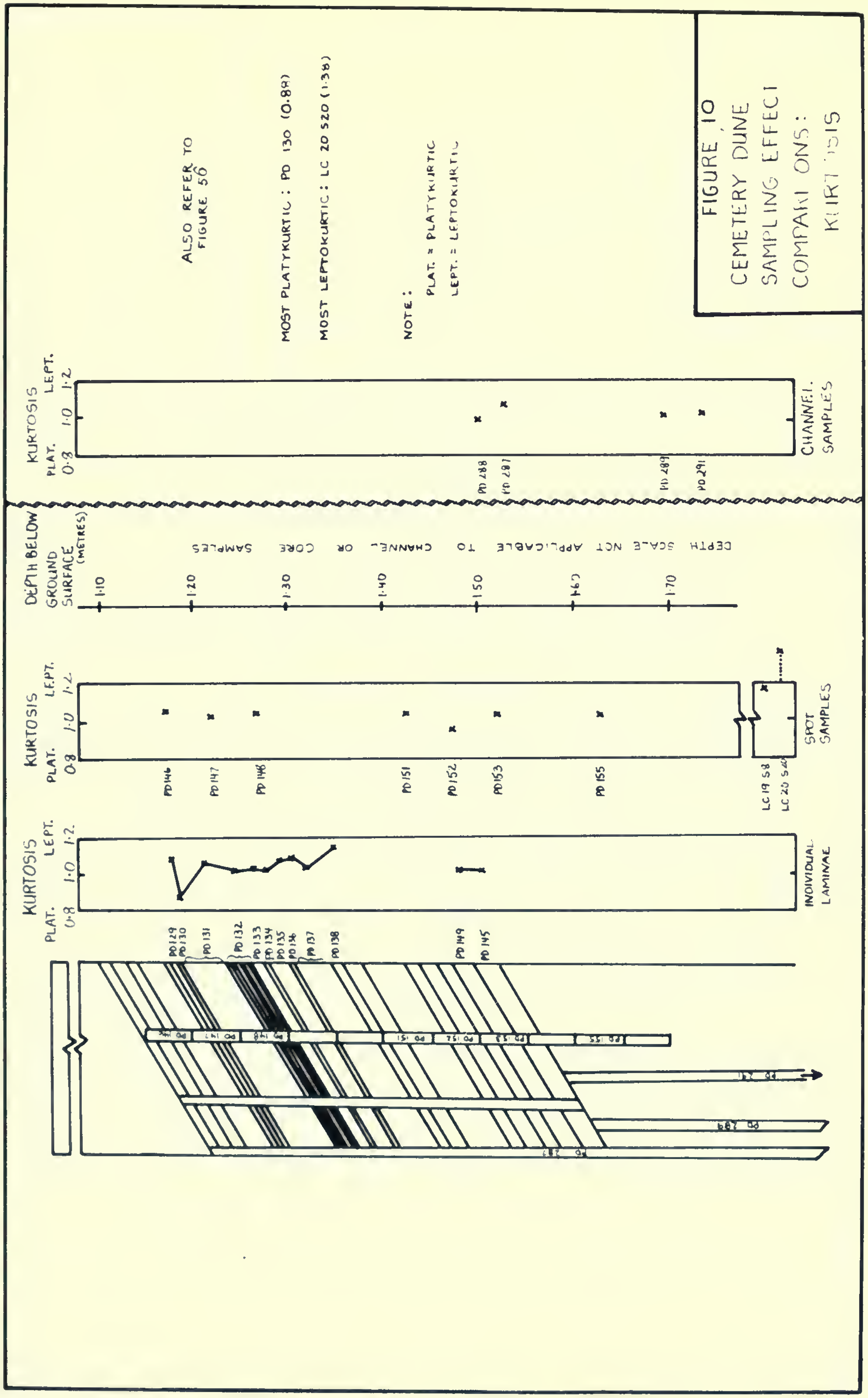
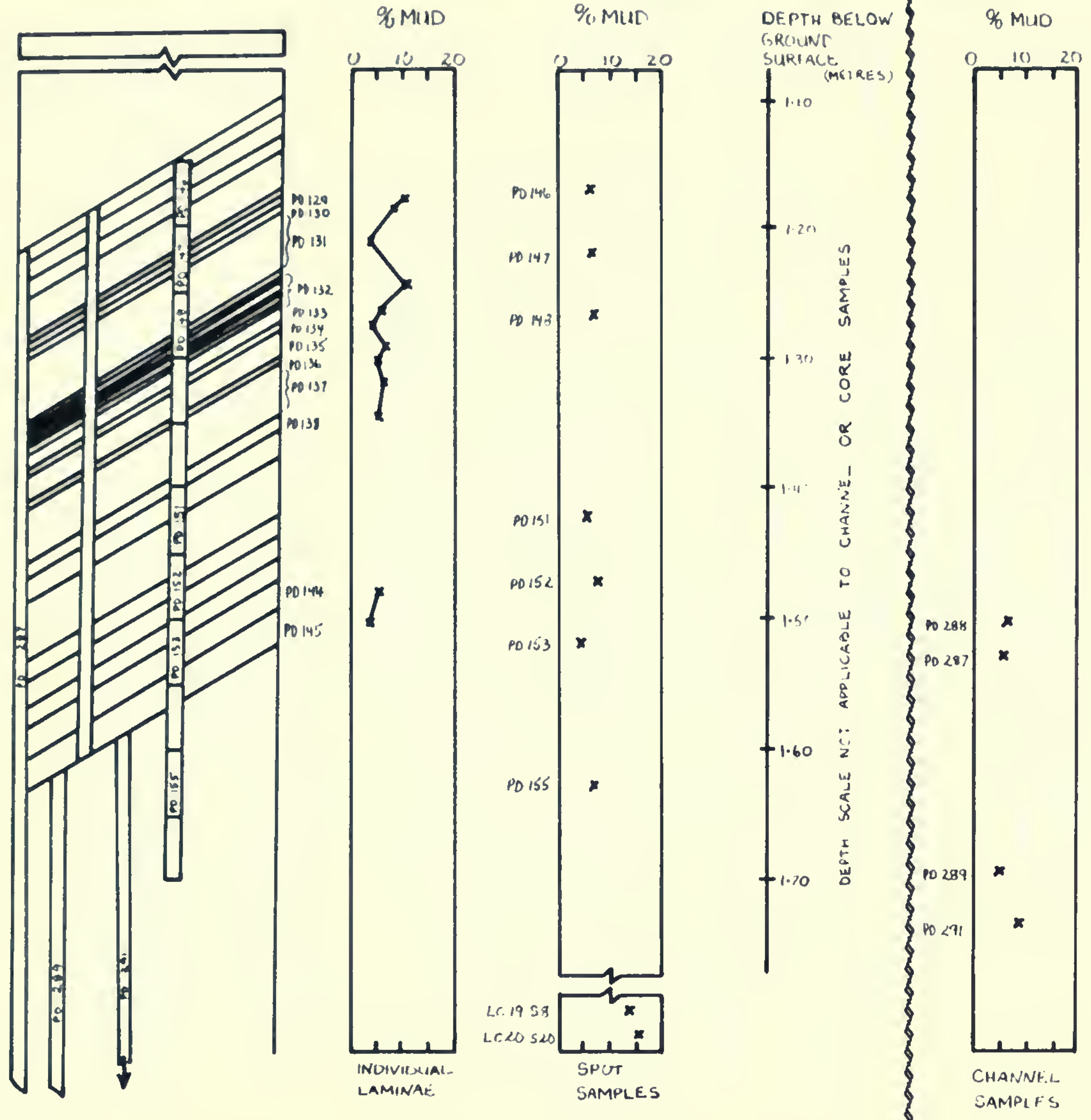


FIGURE 10
CEMETERY DUNE
SAMPLING EFFECT
COMPARISONS :
KURTOSIS



ALSO REFER TO FIGURE 56

LOWEST PERCENTAGE OF MUD : PD 131 (3.98 %)

HIGHEST PERCENTAGE OF MUD : LC 20 S20 (15.84 %)

FIGURE 11
CEMETERY DUNE SAMPLING EFFECT COMPARISONS : % MUD

When comparing samples of weathered and unweathered dune sands, it was noted that carbonate rock particles were absent from the weathered material, and a red coating was present around individual quartz grains. It is not known whether this coating was composed of hematite, or an iron-rich clay. This material was the only evidence of cementing seen in the dune sands, not including the root cast material.

A Note on Graphing and Mapping Procedures

One of the objectives of this thesis was to determine the potential usefulness of various grain size parameters in examining and distinguishing between different surficial deposits, and attempting to clarify their sedimentological environments. Therefore, many combinations of these parameters on maps and graphs were generated, and are reproduced in this thesis. Few of these figures show striking patterns or trends. This is a function of two aspects. First, the use of grain size analysis for the purposes mentioned above may produce data that results in only subtle impressions. The second point to consider is the fact that, in a small sedimentological system such as this thesis area, the sediments are intimately related and may not have been active for a sufficient length of time to come to equilibrium with their environment of deposition. This would result in very similar grain size parameters for most sediments.

Although some of the maps and graphs produced in this thesis may not show obvious trends, they are included so as to provide complete documentation of possible combinations of parameter displays. The full sets of possible combinations of parameters also make it possible to directly compare results from all the attempts at distinguishing patterns.

TERNARY GRAPHS OF SEDIMENT TEXTURE

These graphs (Figures 13 to 16) compare the textural characteristics of the thesis samples. Figure 12 shows the textural boundaries outlined by Shepard (1954) that were used for the purposes of this study. It should be noted that the "100% Sand" corner actually represents the percentage weight of sand plus gravel in the sample, if it contains gravel.

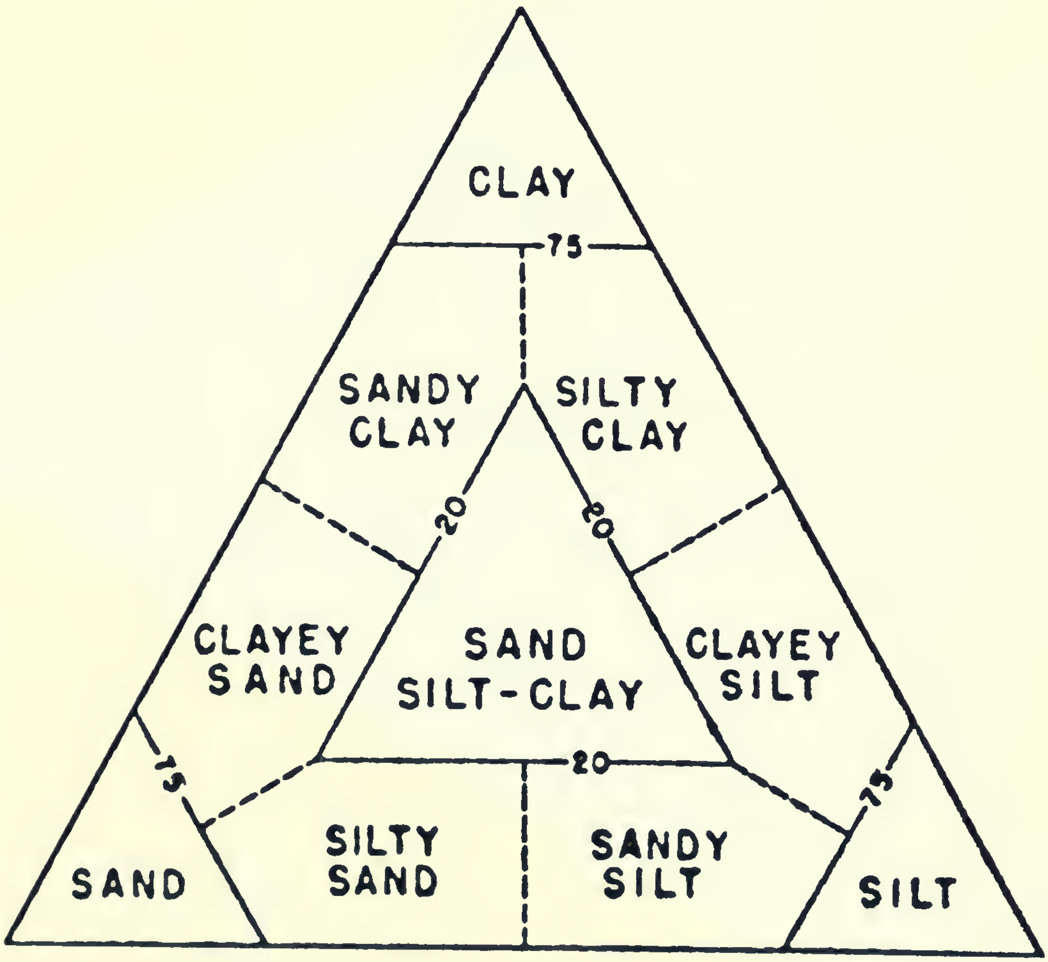


Figure 12: Ternary Graph: Sand Texture Boundaries

(Shepard, 1954)

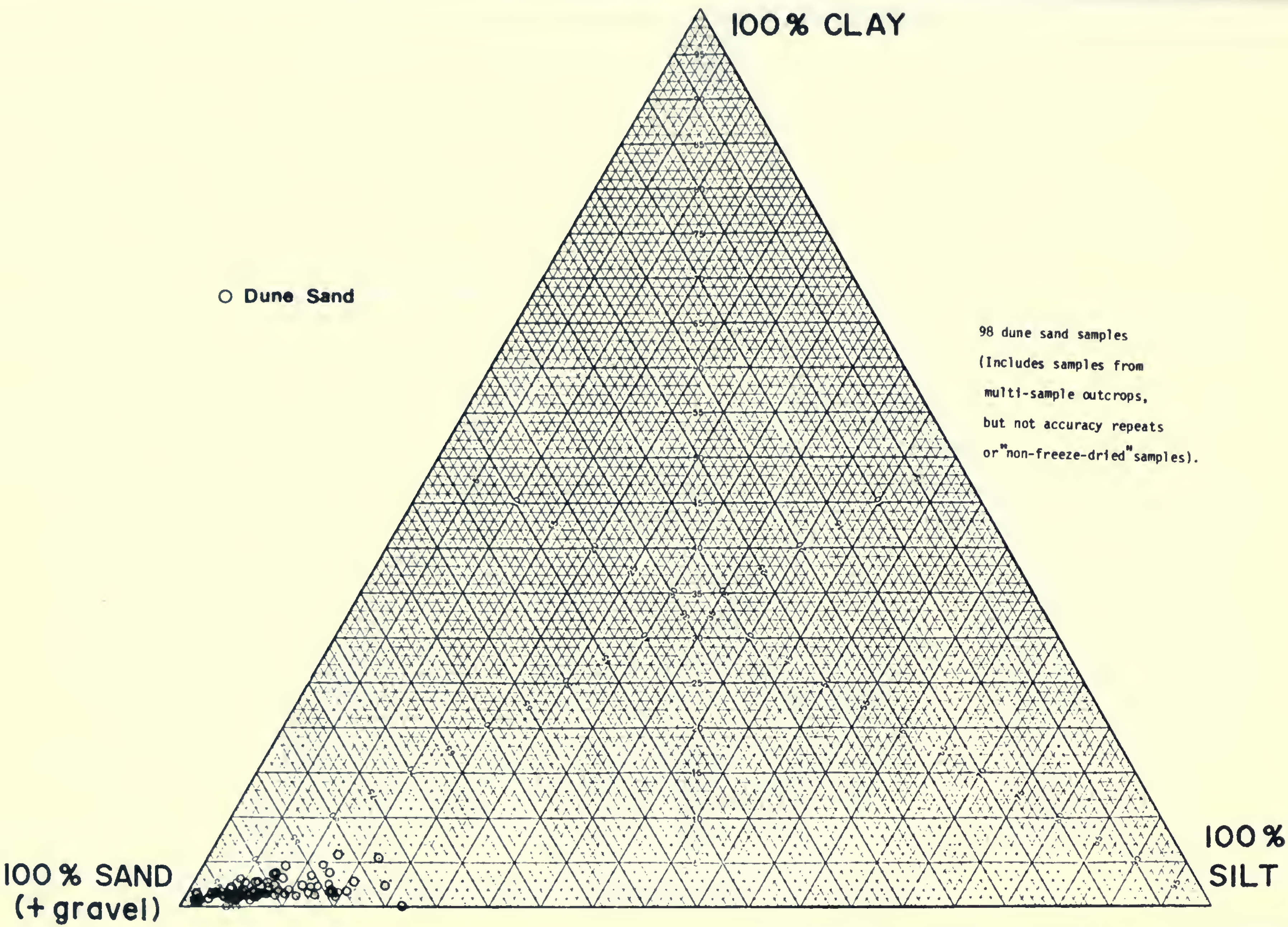


Figure 13: Ternary Graph: Dune Sand Samples

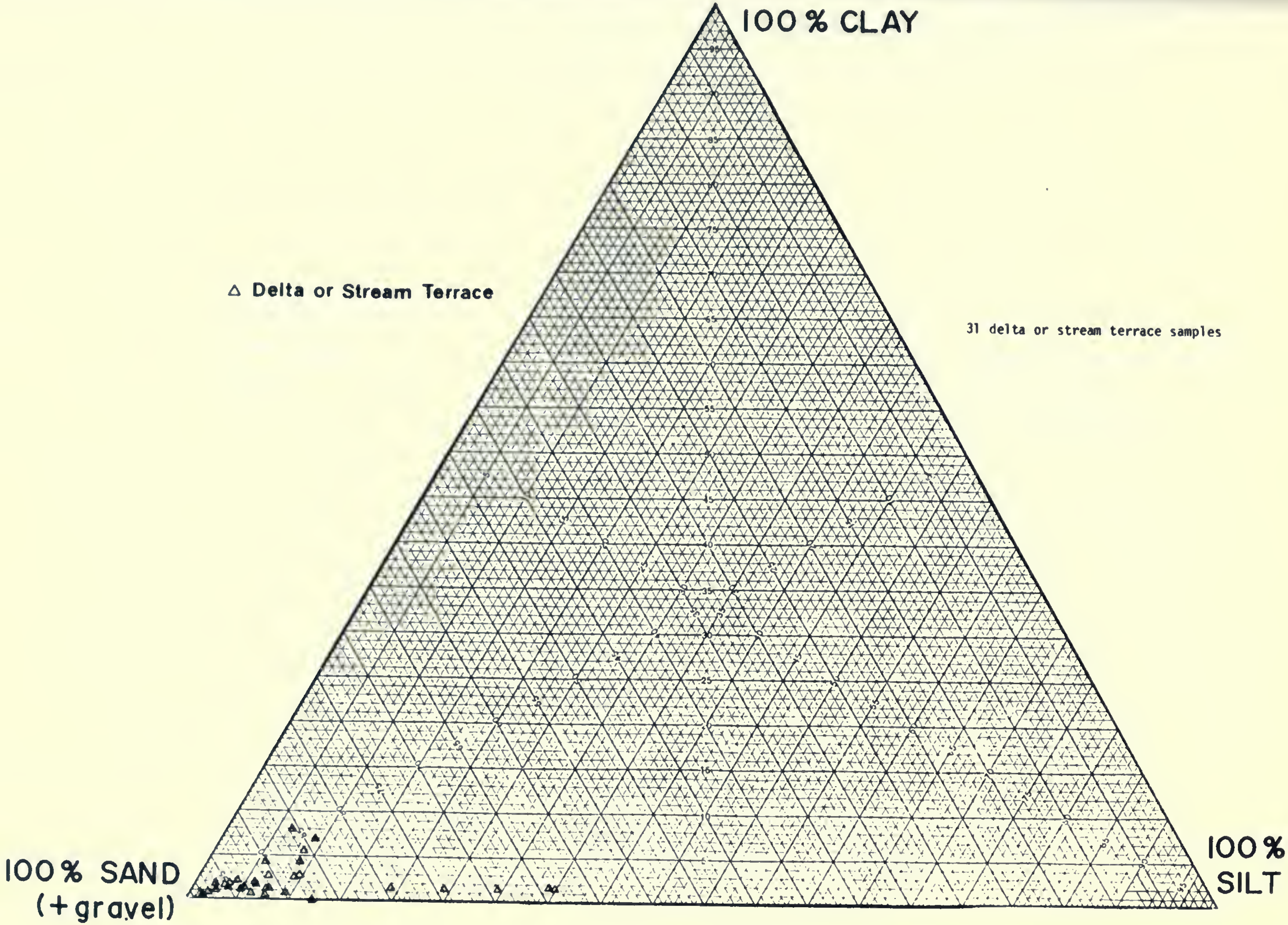


Figure 14: Ternary Graph: Delta or Stream Terrace Samples

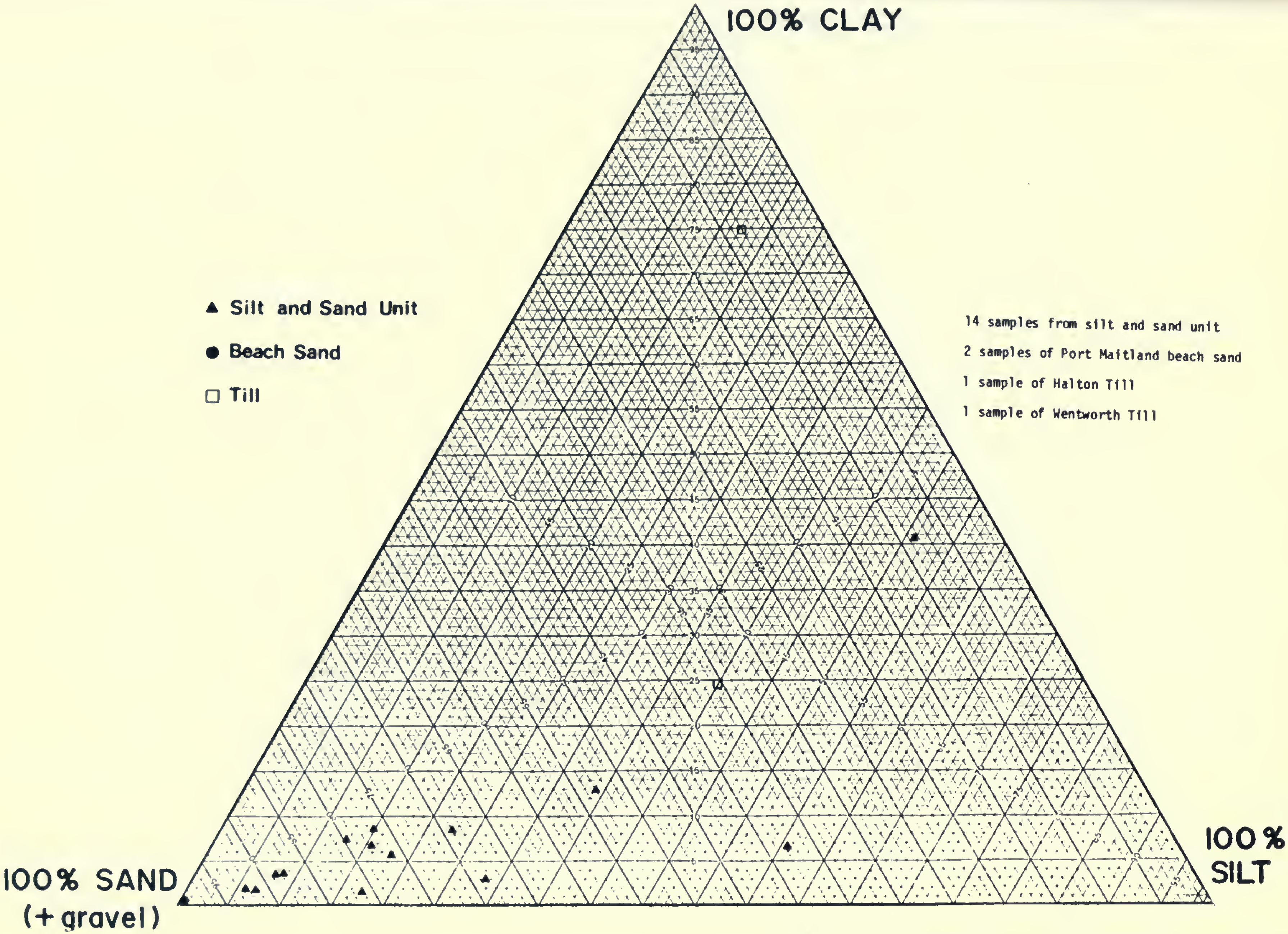


Figure 15: Ternary Graph: Silt and Sand Unit; Beach Sand; Till Samples

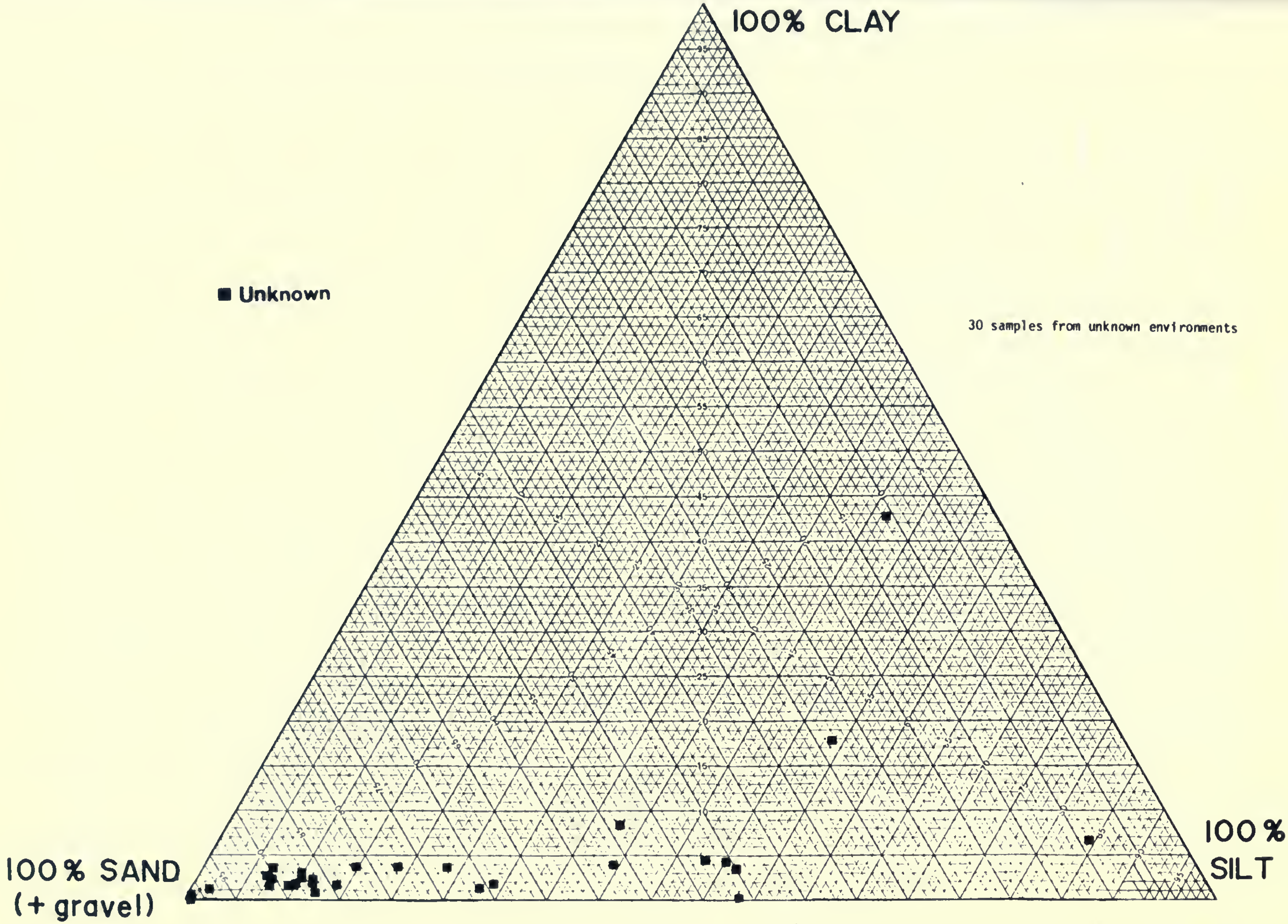


Figure 16: Ternary Graph: Unknown Samples

GRAIN SIZE STATISTICS MAPS

The following maps (Figures 17 to 23) illustrate the areal distribution of various grain size parameters of sediment samples from the thesis area. Sample numbers are shown on Figure 5, and brief descriptions of the samples and their locales are given in Appendix I. It should be noted that even though the mapped samples may have been collected from a variety of deposit types, most of them are assumed to have come from the same basic source, that being the delta deposit at Dunnville. The exceptions are samples from lake bottom deposits, usually at the fringe of the mapped area. The assumption noted above makes the comparing of statistics between mapped samples possible and also allows gross interpretations to be made.

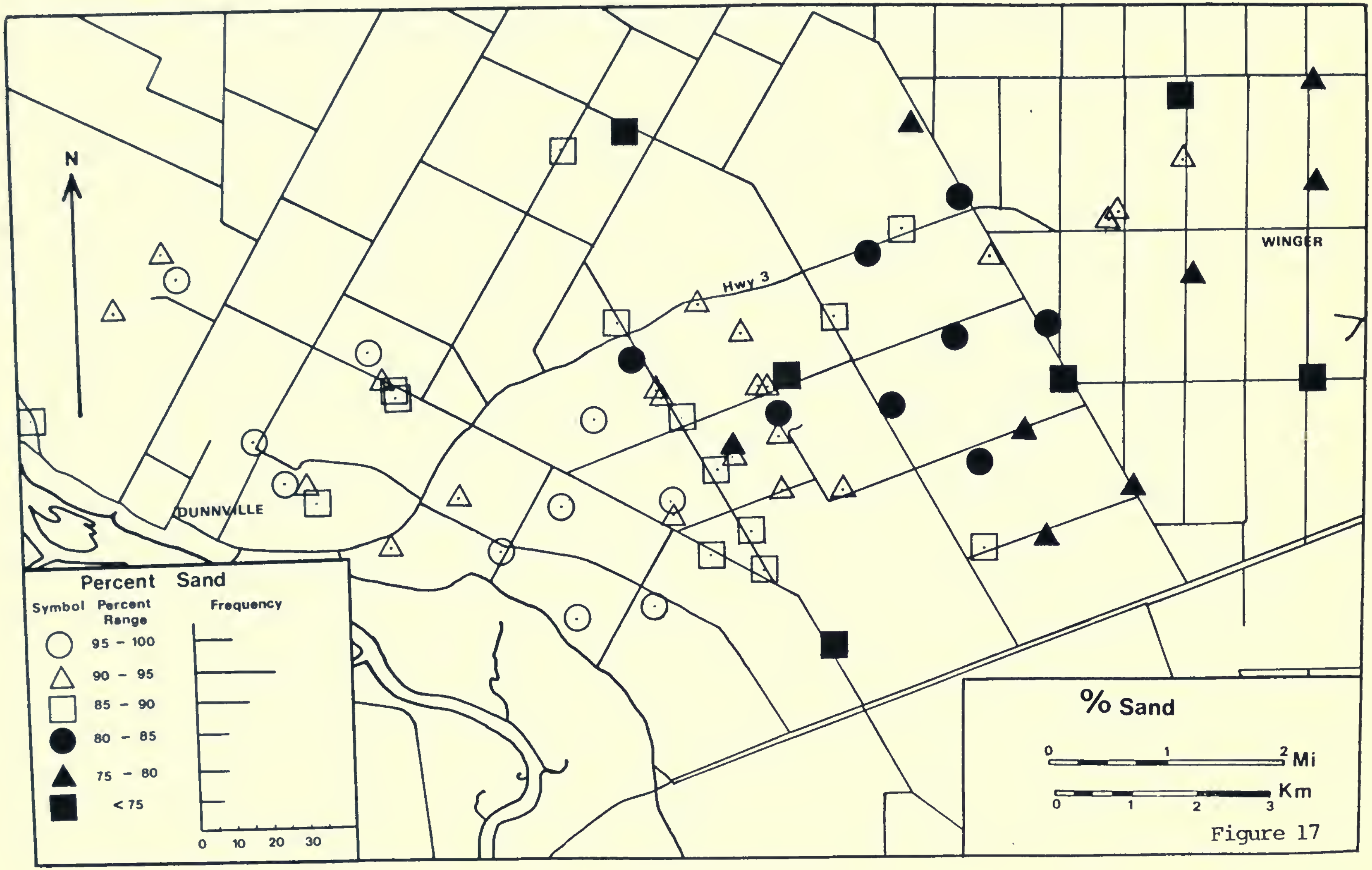
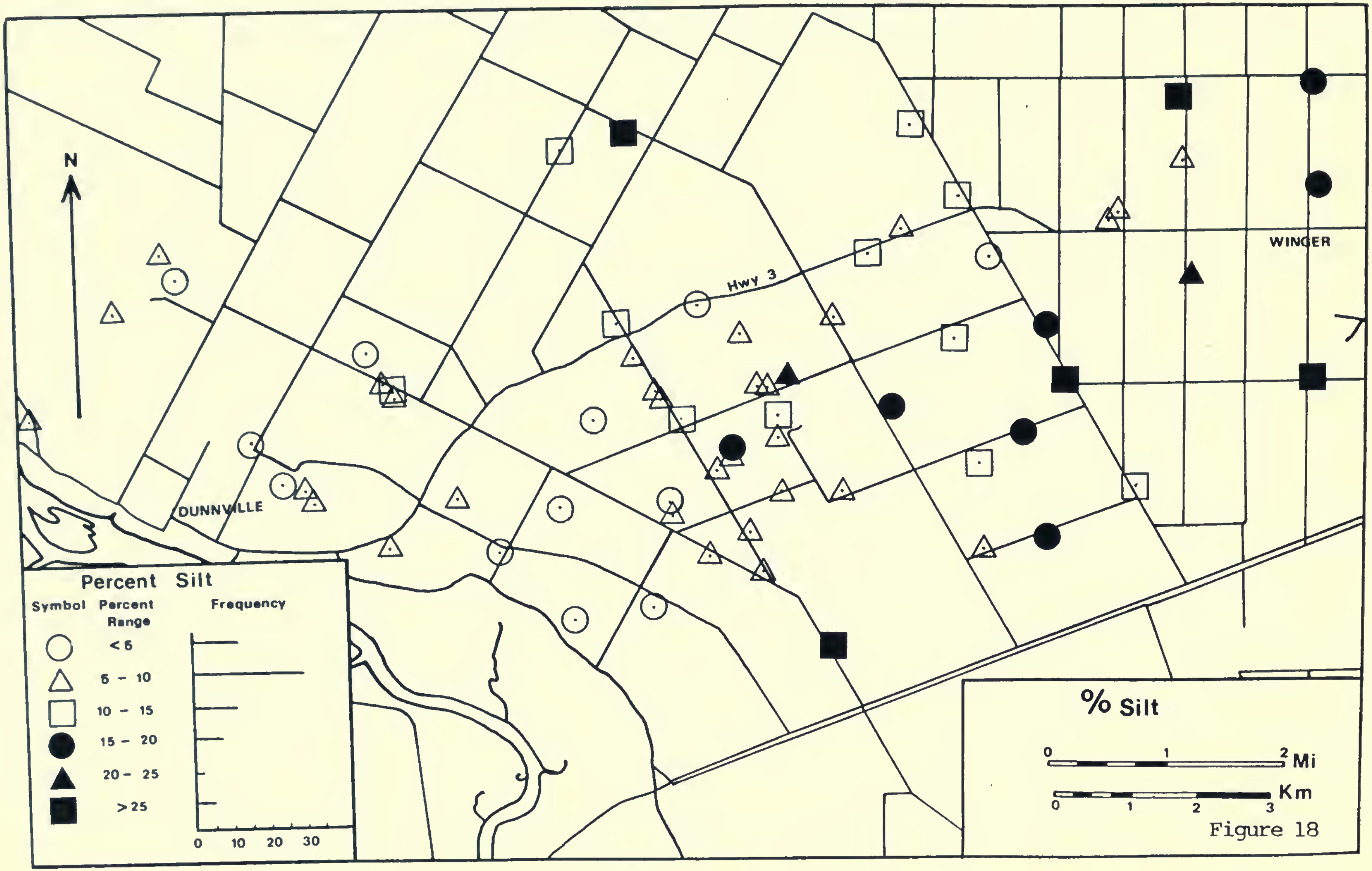

N
WINGER
Hwy 3
DUNNVILLE
Percent Sand
Symbol
Percent Range
Frequency
95 - 100
90 - 95
85 - 90
80 - 85
75 - 80
< 75
0
10
20
30
% Sand
0
1
2
Mi
0
1
2
3
Km

Figure 17


N
WINGER
Hwy 3
DUNNVILLE
Percent Silt
Symbol
Percent Range
Frequency
< 5
5 - 10
10 - 15
15 - 20
20 - 25
> 25
0
10
20
30
% Silt
0
1
2
Mi
0
1
2
3
Km
Figure 18

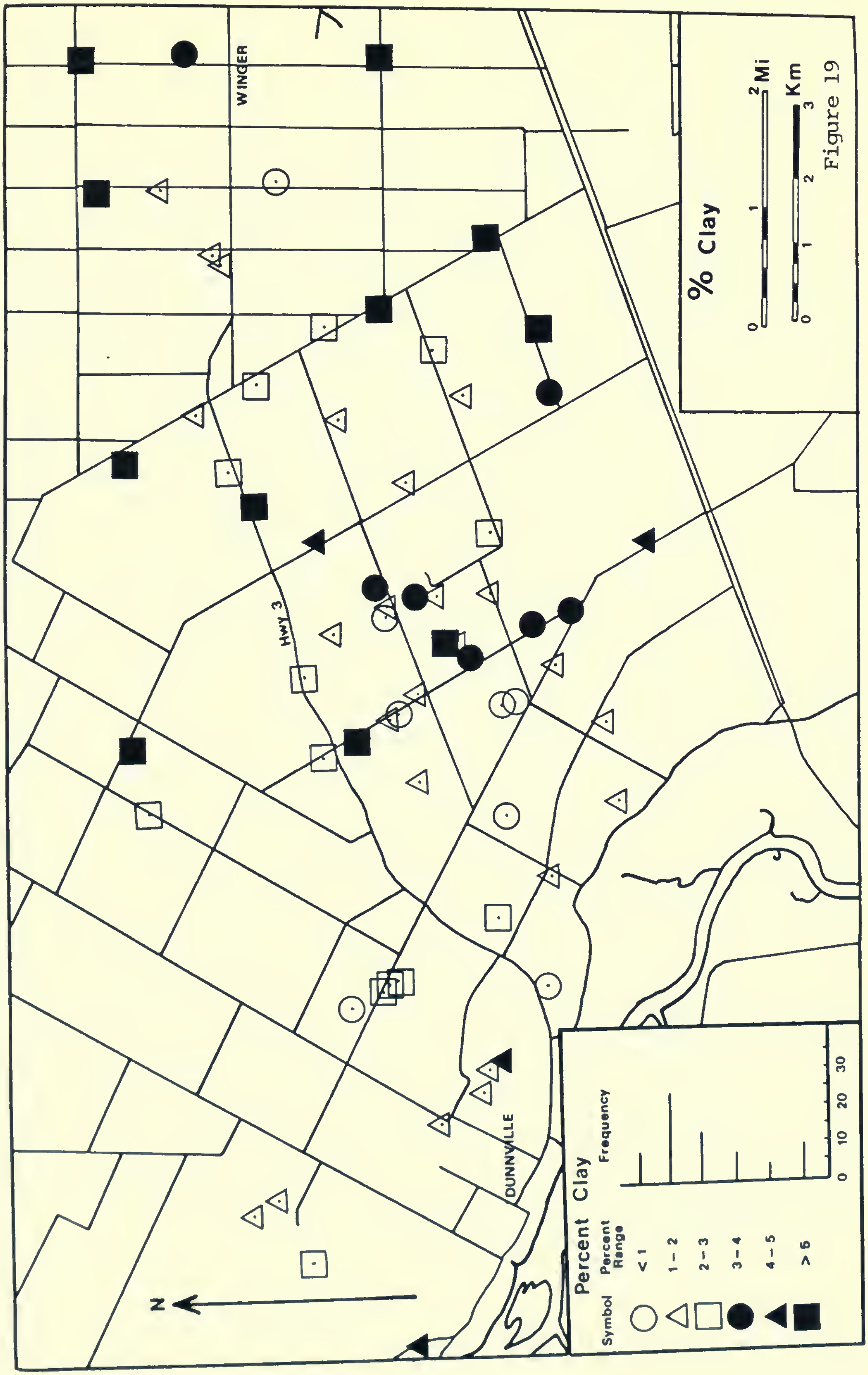

WINGER
Hwy 3
DUNNVILLE
N
% Clay
0 1 2 Mi
0 1 2 3 Km
Percent Clay
Symbol
Percent Range
< 1
1 – 2
2 – 3
3 – 4
4 – 5
> 6
Frequency
0 10 20 30

Figure 19

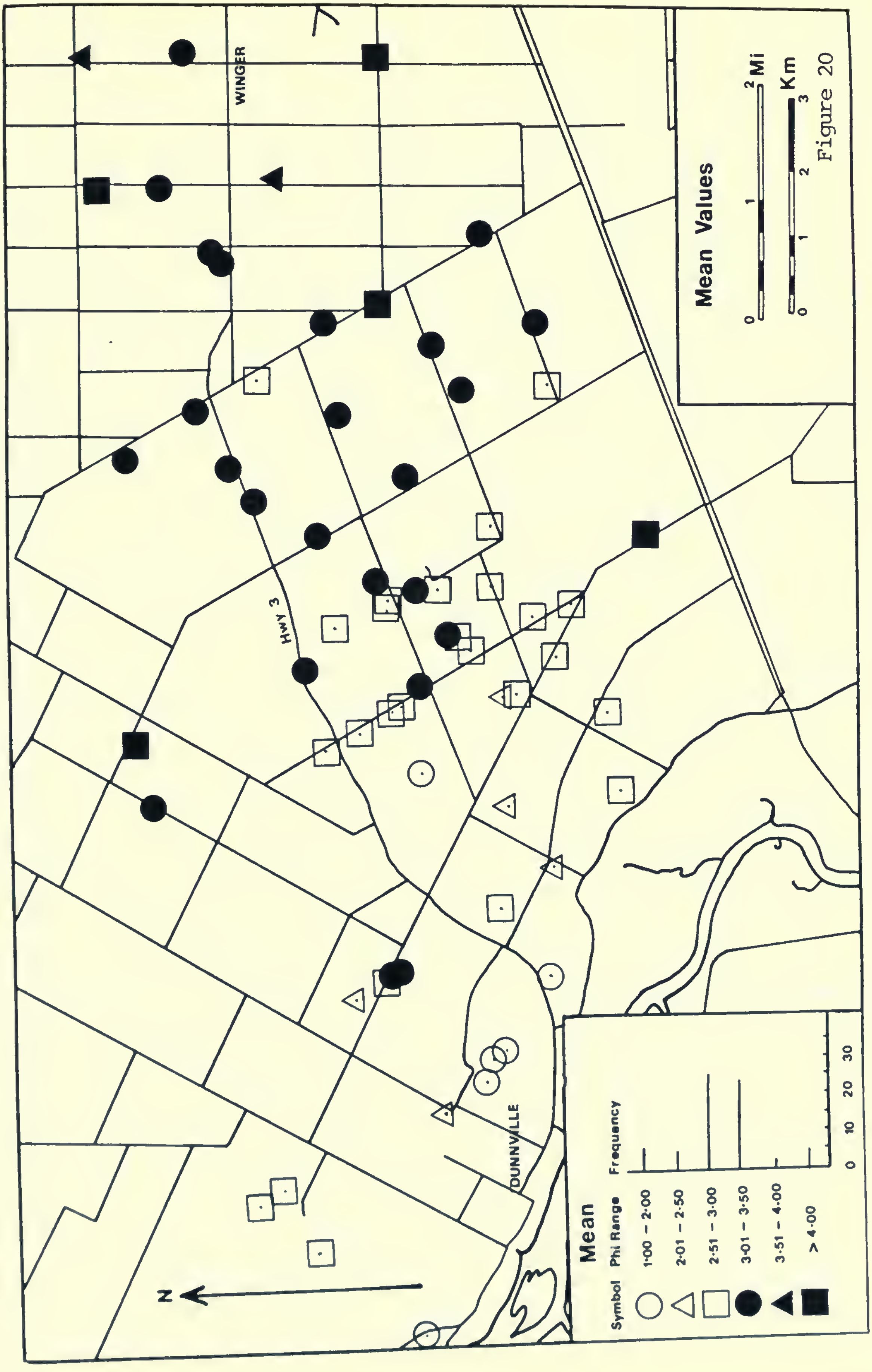

WINGER
Hwy 3
DUNNVILLE
N
Mean Values
0 1 2 Mi
0 1 2 3 Km
Mean
Symbol
Phi Range
1·00 – 2·00
2·01 – 2·50
2·51 – 3·00
3·01 – 3·50
3·51 – 4·00
> 4·00
Frequency
0 10 20 30

Figure 20

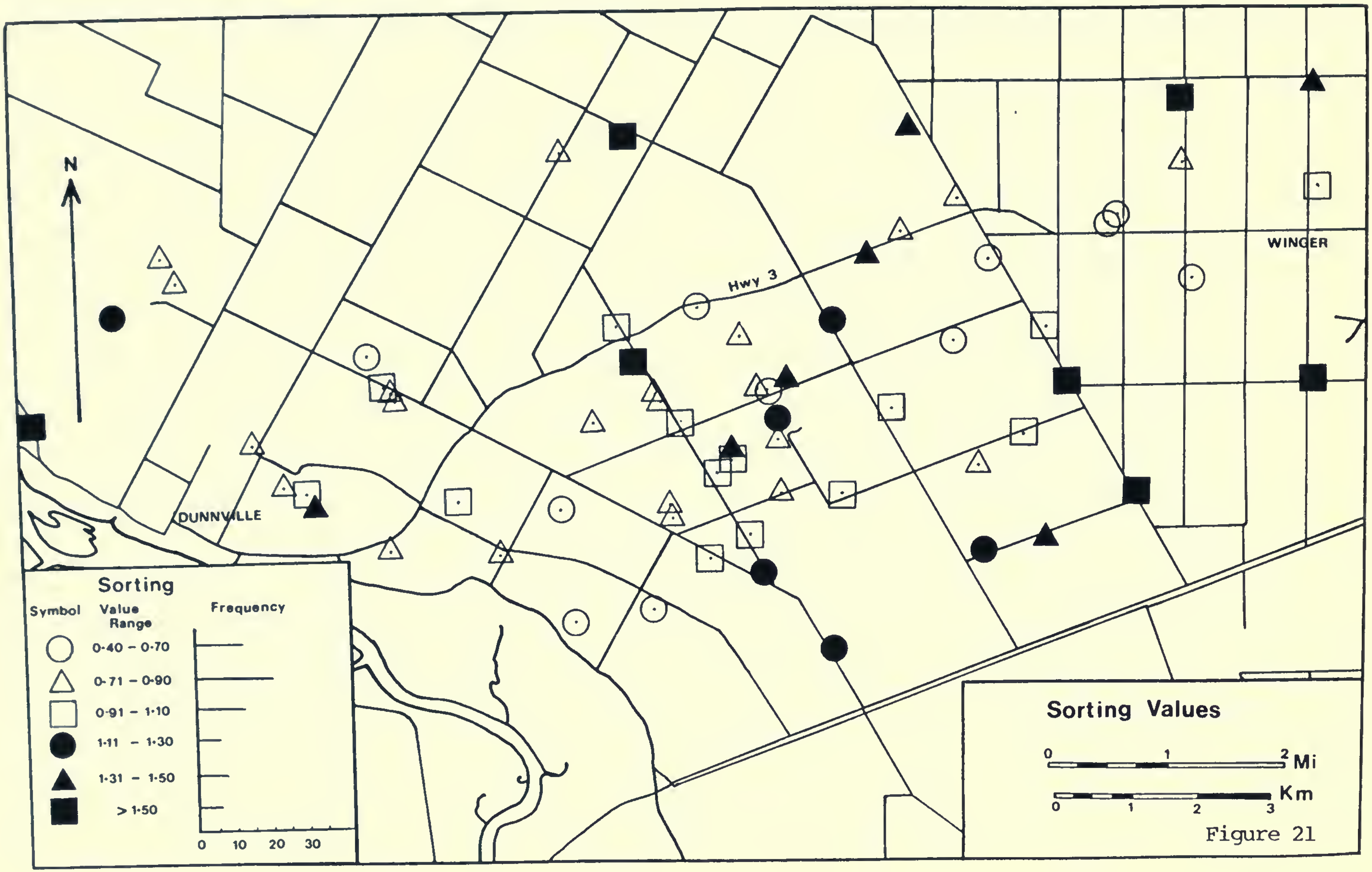

N
WINGER
Hwy 3
DUNNVILLE
Sorting
Symbol
Value Range
Frequency
0·40 – 0·70
0·71 – 0·90
0·91 – 1·10
1·11 – 1·30
1·31 – 1·50
> 1·50
0
10
20
30
Sorting Values
0
1
2 Mi
0
1
2
3 Km

Figure 21

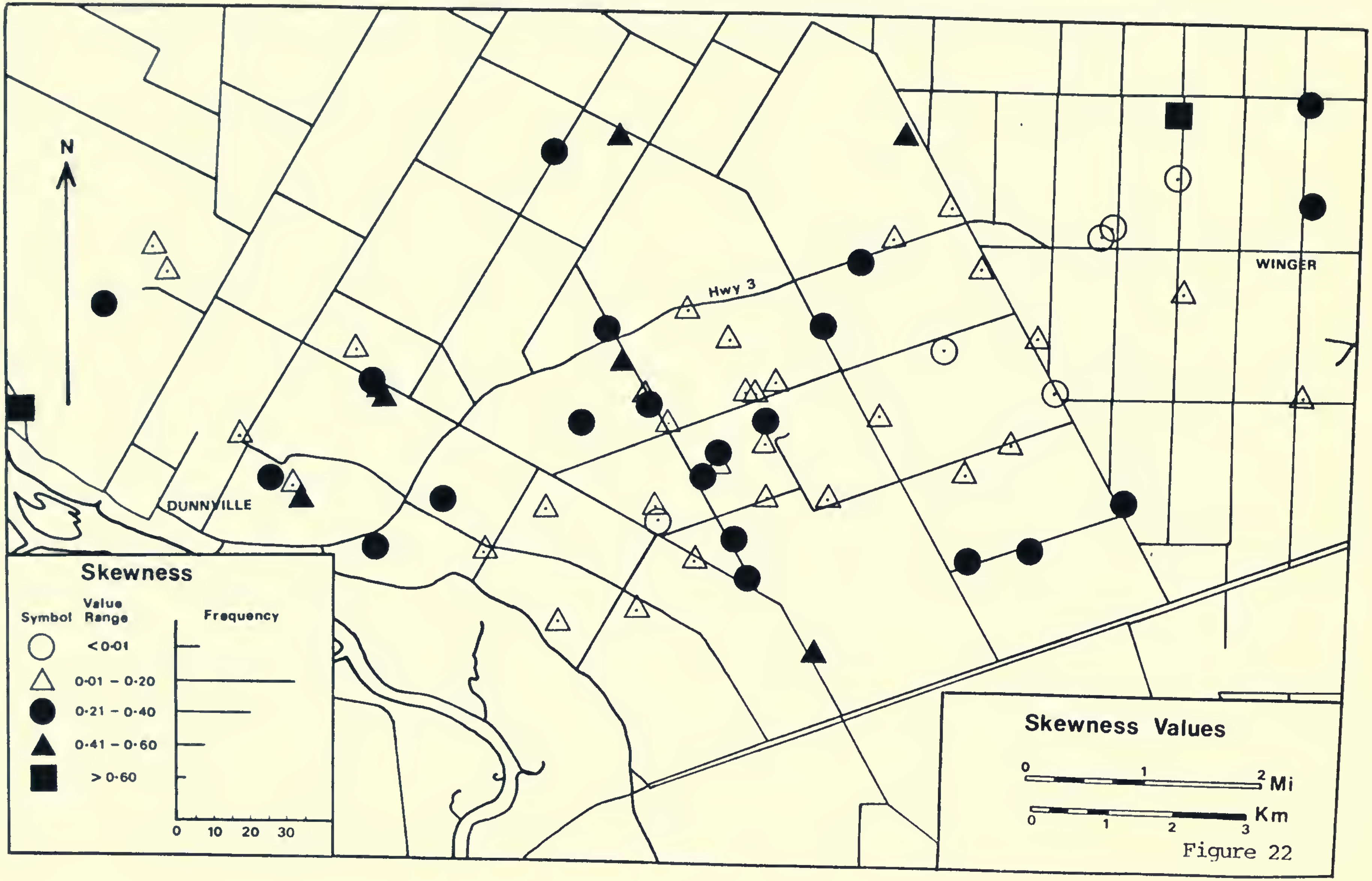

N
WINGER
Hwy 3
DUNNVILLE
Skewness
Symbol
Value Range
Frequency
< 0·01
0·01 – 0·20
0·21 – 0·40
0·41 – 0·60
> 0·60
0
10
20
30
Skewness Values
0
1
2 Mi
0
1
2
3 Km

Figure 22

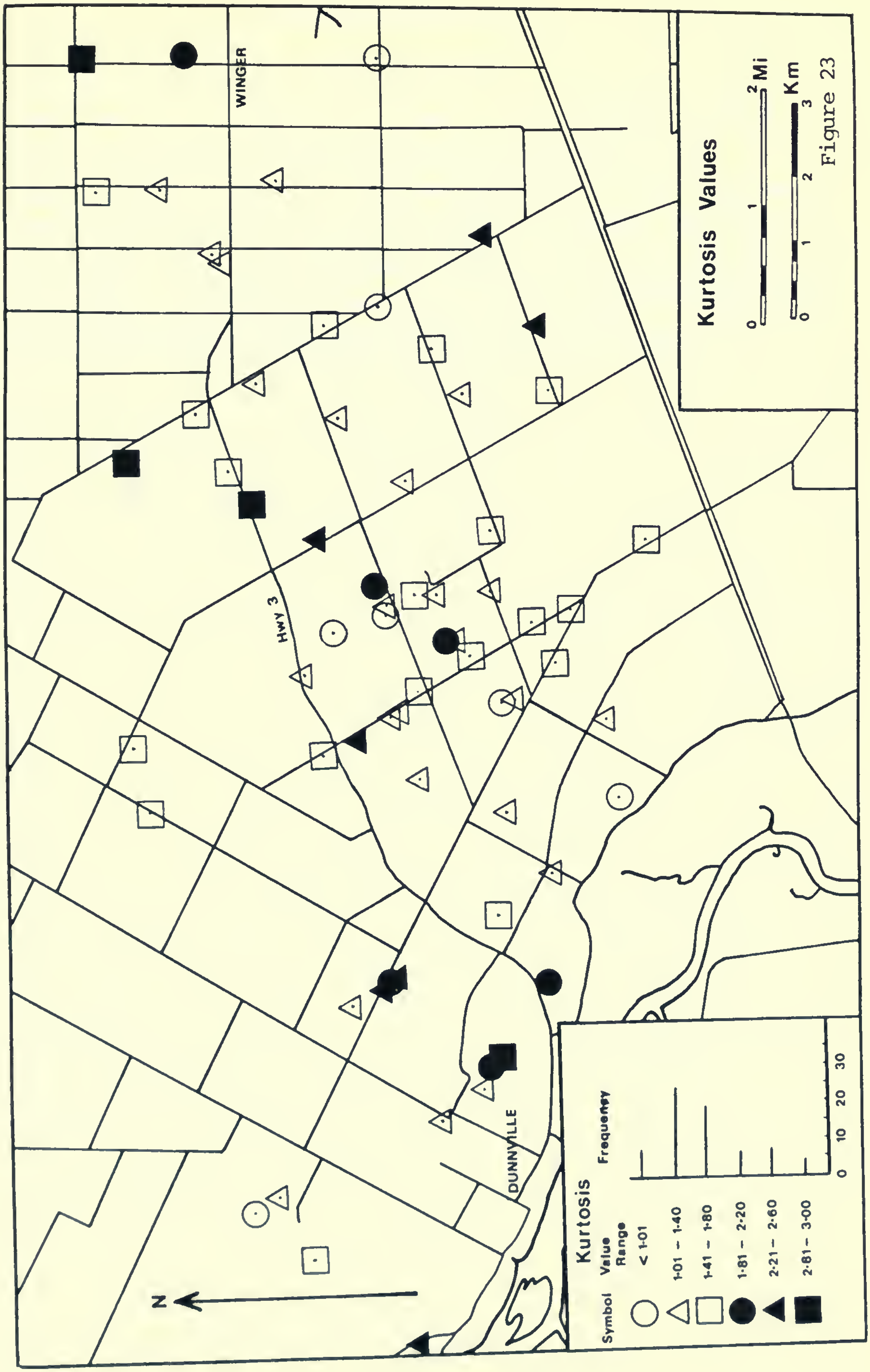

Kurtosis Values
0
1
2 Mi
0
1
2
3
Km
WINGER
Hwy 3
DUNNVILLE
N
Kurtosis
Symbol
Value Range
< 1·01
1·01 – 1·40
1·41 – 1·80
1·81 – 2·20
2·21 – 2·60
2·61 – 3·00
Frequency
0
10
20
30

Figure 23

PARAMETER TREND GRAPHS

The following diagrams (Figures 24 to 30) illustrate trends of parameter values of samples from west to east across the thesis area. These graphs were constructed by projecting sample locations onto an east-west line and then plotting their distance from the western edge of the map versus the parameter value for that sample. These parameter trend graphs assist in a somewhat more objective analysis of parameter trends across the thesis area than the grain size statistic maps on the preceding pages.

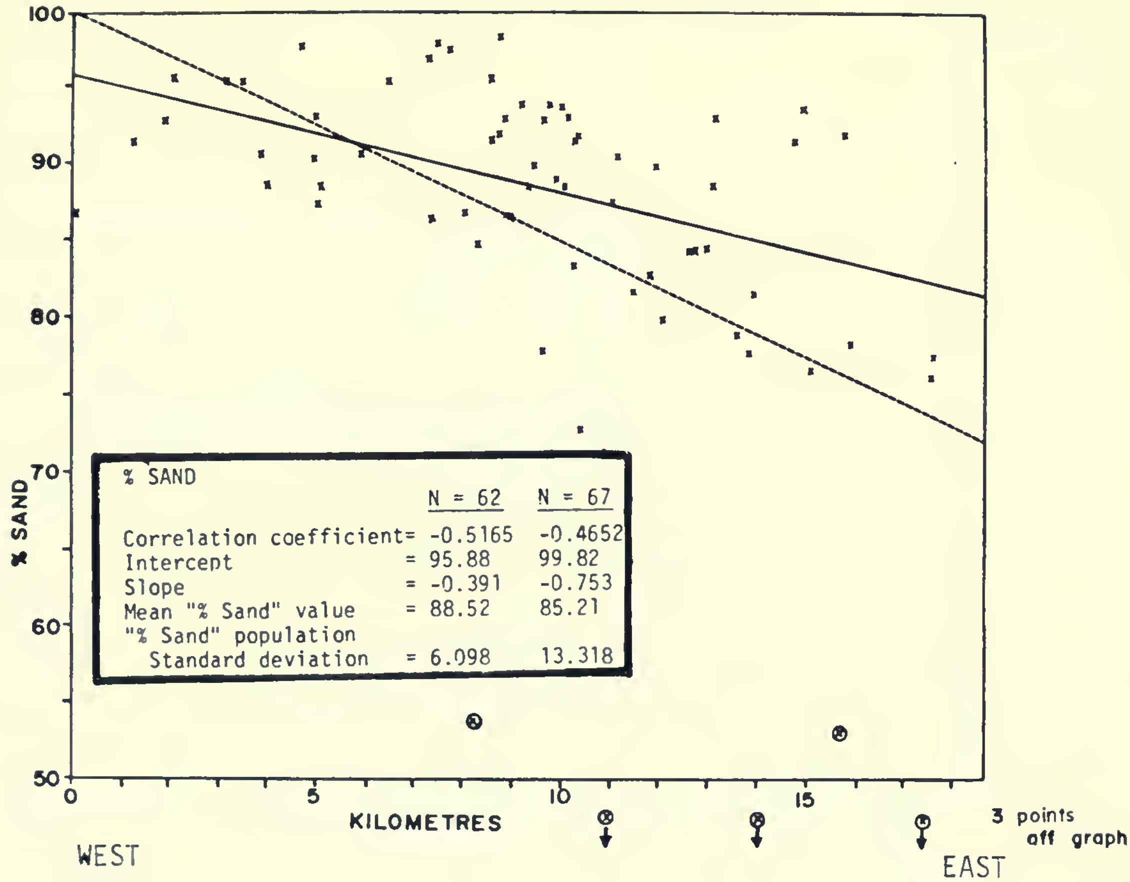
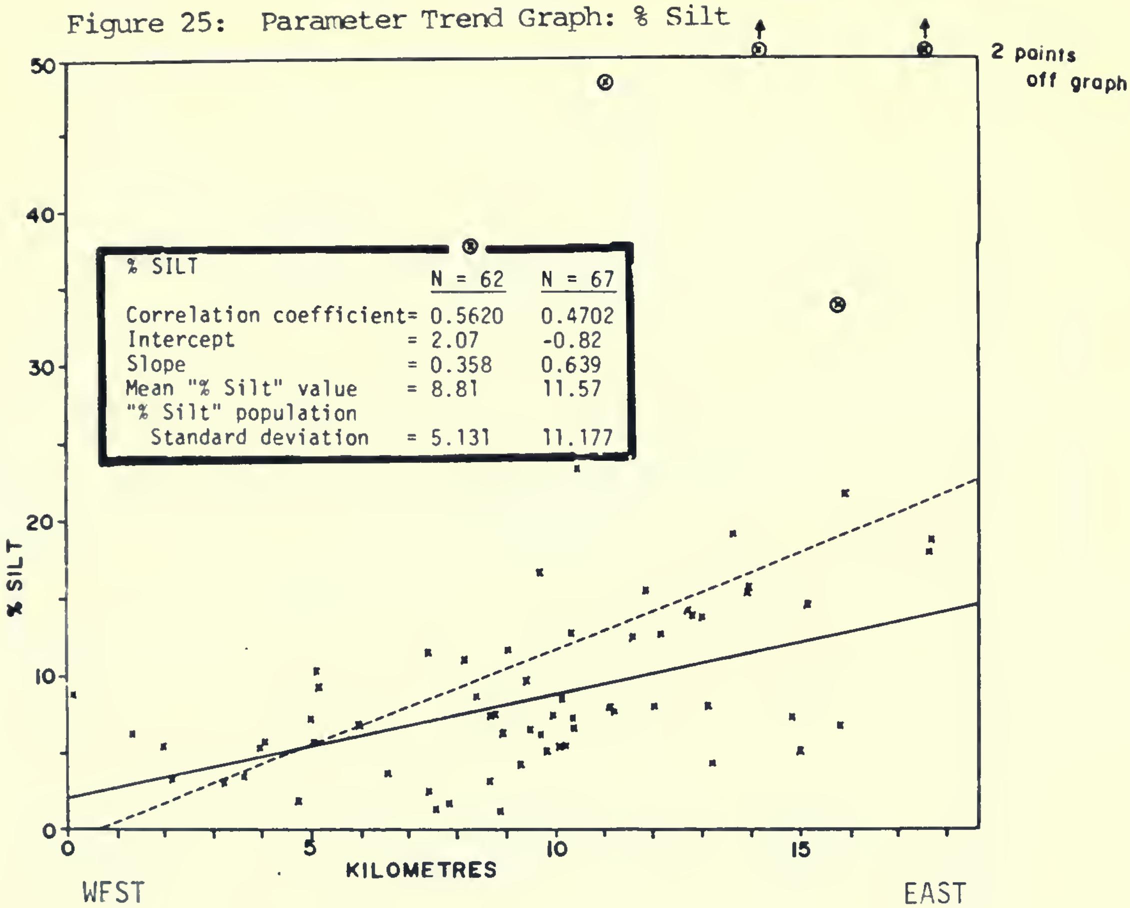


Figure 24: Parameter Trend Graph: % Sand

On this graph, as well as the following 6 graphs, the inclined dashed line represents the "best fit" line for all data points (ie. N=67). This includes the five circled points that represent samples from lake bottom deposits. The solid inclined line represents the "best fit" line for the 62 samples obtained from the Dunnville deltaic/aeolian system only (ie. N=62). By comparing the two inclined lines, as well as the two columns of population statistics on each graph, it can be seen how the presence of the five "lake bottom" samples alters the values obtained.

Figure 25: Parameter Trend Graph: % Silt



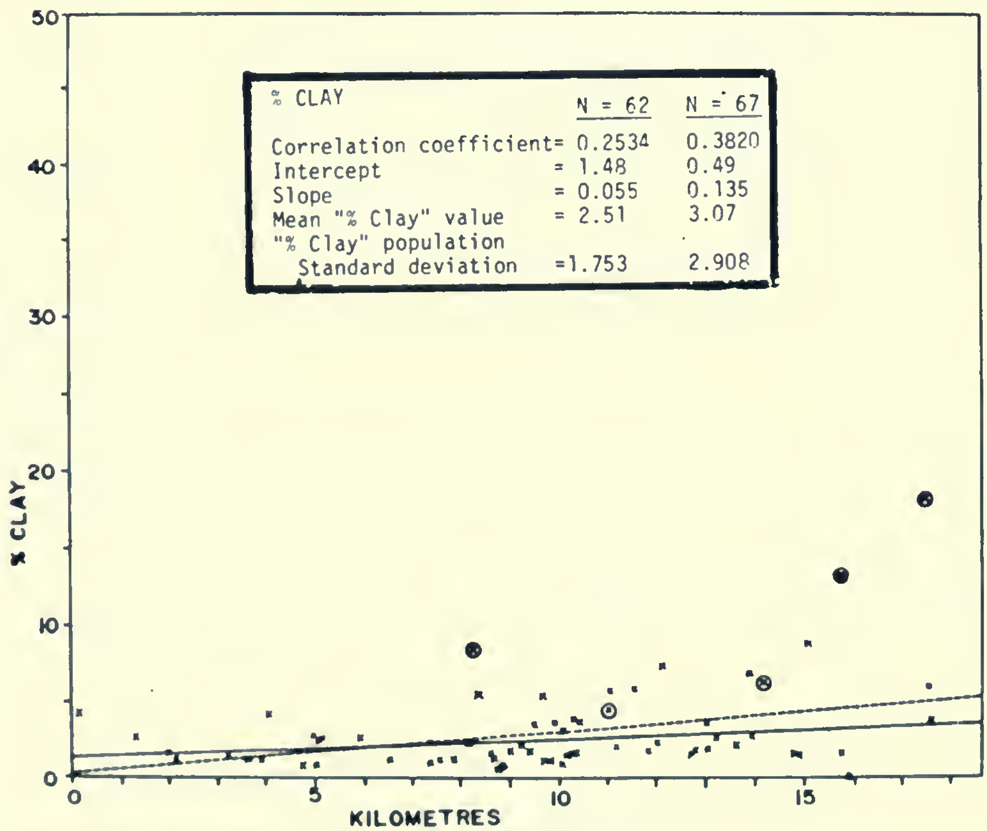
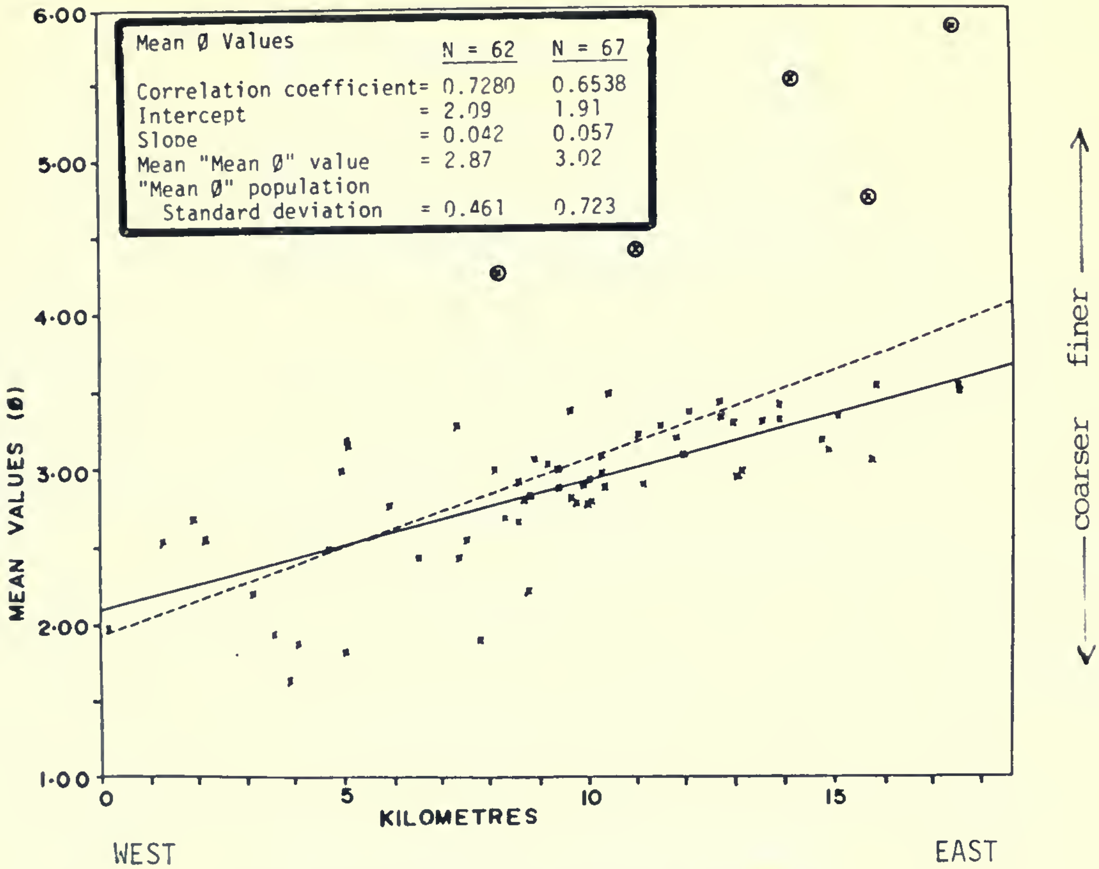


Figure 26: Parameter Trend Graph: % Clay

Figure 27: Parameter Trend Graph: Mean Ø Values



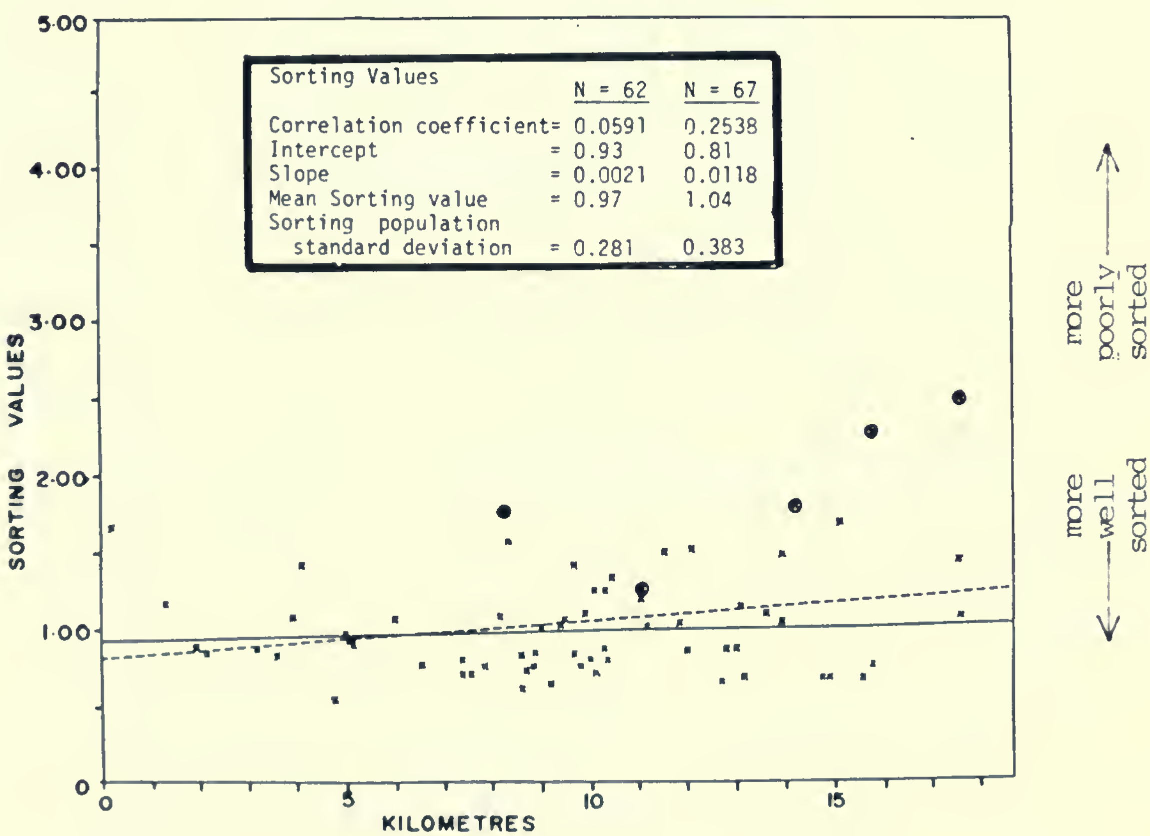
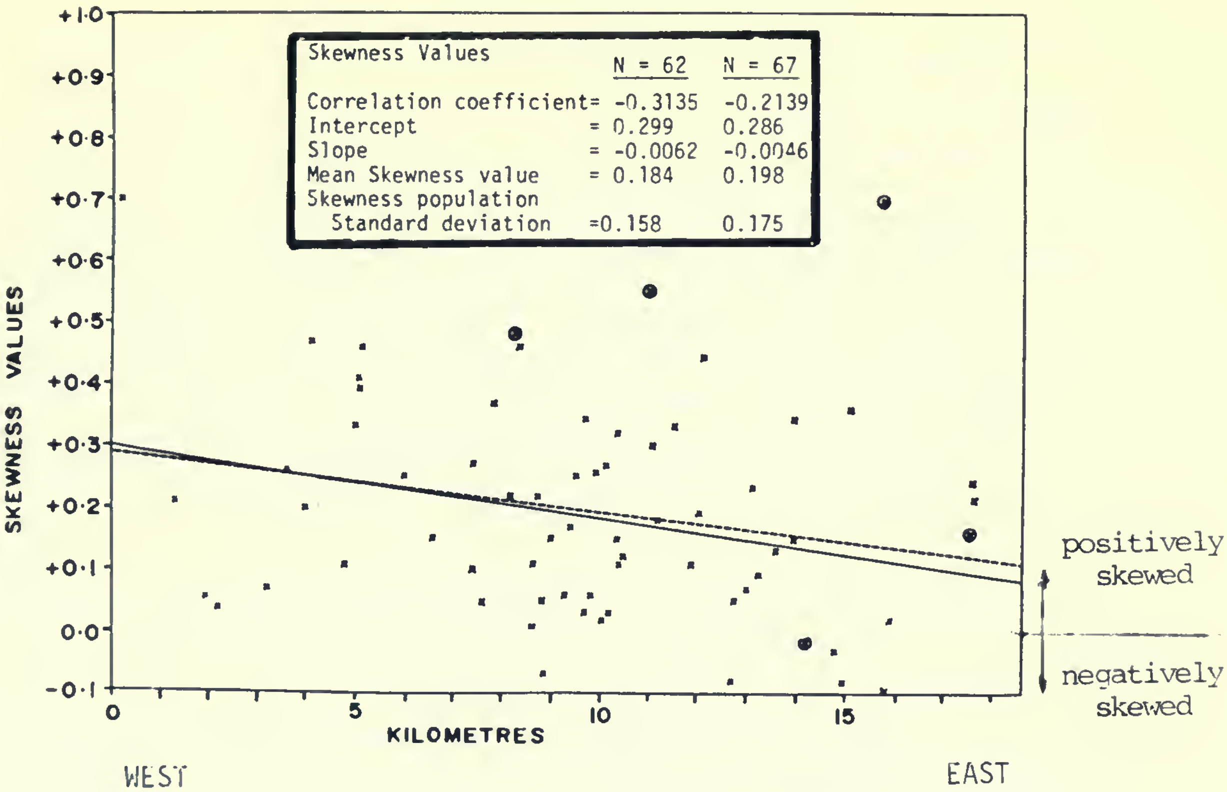


Figure 28: Parameter Trend Graph: Sorting Values

Figure 29: Parameter Trend Graph: Skewness Values



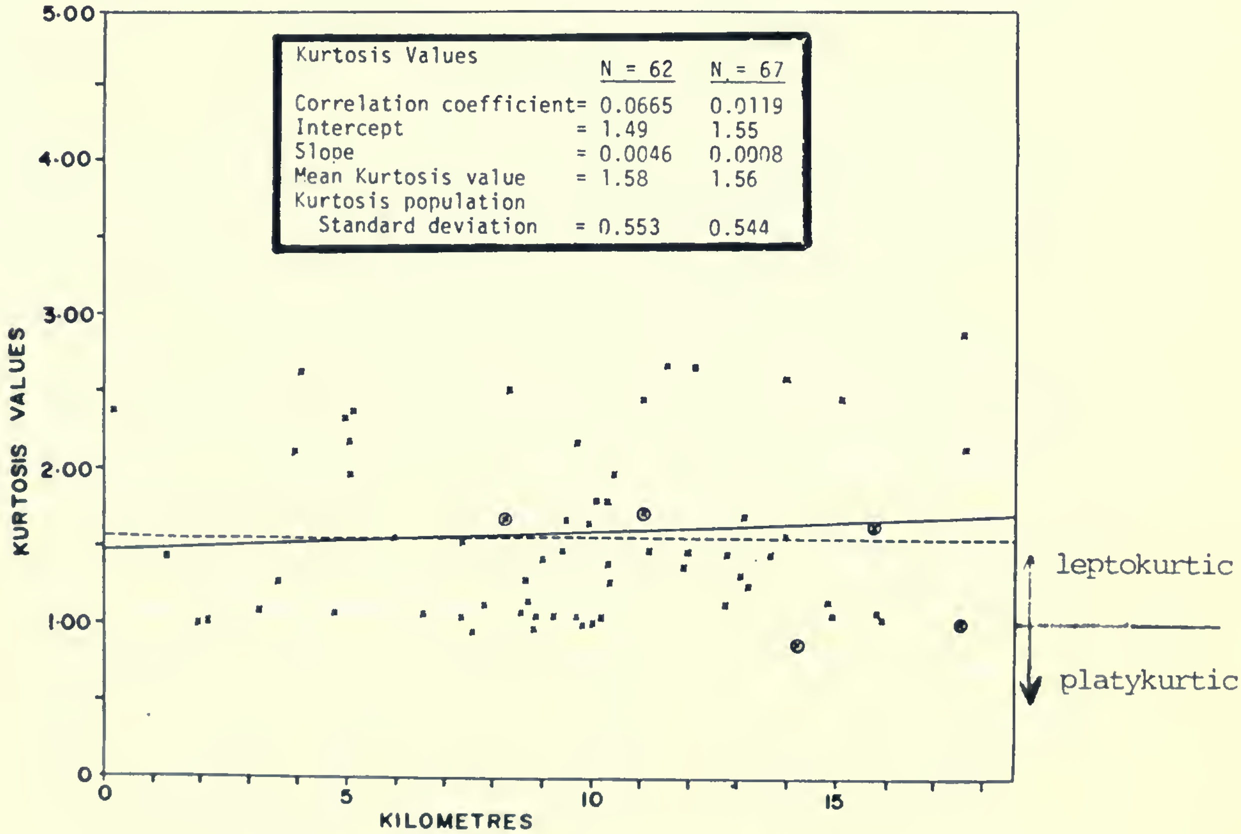


Figure 30: Parameter Trend Graph: Kurtosis Values

BIVARIATE PARAMETER GRAPHS

The following bivariate plots (Figures 31 to 36) represent an attempt to distinguish between the three main units in the thesis area, ie.: dune sand, delta or stream terrace sand, and samples of the "silt and sand" unit. It should also be noted that the graphing patterns that may be indicated are valid for the samples taken in the thesis area, and are not meant to support nor disprove Mason and Folk's (1958), Friedman's (1961) or any other author's published depositional environment boundaries, nor to establish "new" boundaries. Appendix IV has a discussion on comparing Folk and Ward parameters to moment statistics.

Comparison graphs of moment measure values with Folk and Ward graphic parameters are included here as Figures 37 to 40. No correlation coefficient values or other statistical values are calculated for Figures 37 to 40, as they are only meant to illustrate the gross differences possible between the two types of parameters.

The bivariate plots presented here illustrate the following general features of the thesis samples. The mean grain size of dune sediments (white circles) is rarely outside the 2 to 3 phi range, and they are generally positively skewed or have near-normal skewness. Most of the dune sands appear to be moderately sorted. Samples from all recognizable depositional environments seem to have a grain size distribution that is either near normal or leptokurtic. The two beach sand samples (black circles) and the two till samples (white squares) usually plot in an area removed from the large majority of the remaining samples. With a few notable exceptions, samples from the "silt and sand" unit appear to follow the same trends of distribution as dune samples. Unknown samples plot indiscriminantly within the general limits established by all other samples. The delta or stream terrace samples show a larger spread of data points than other environments, and occasionally stand out against the general background.

Figure 31: Bivariate Parameter Graph:
Mean vs. Skewness

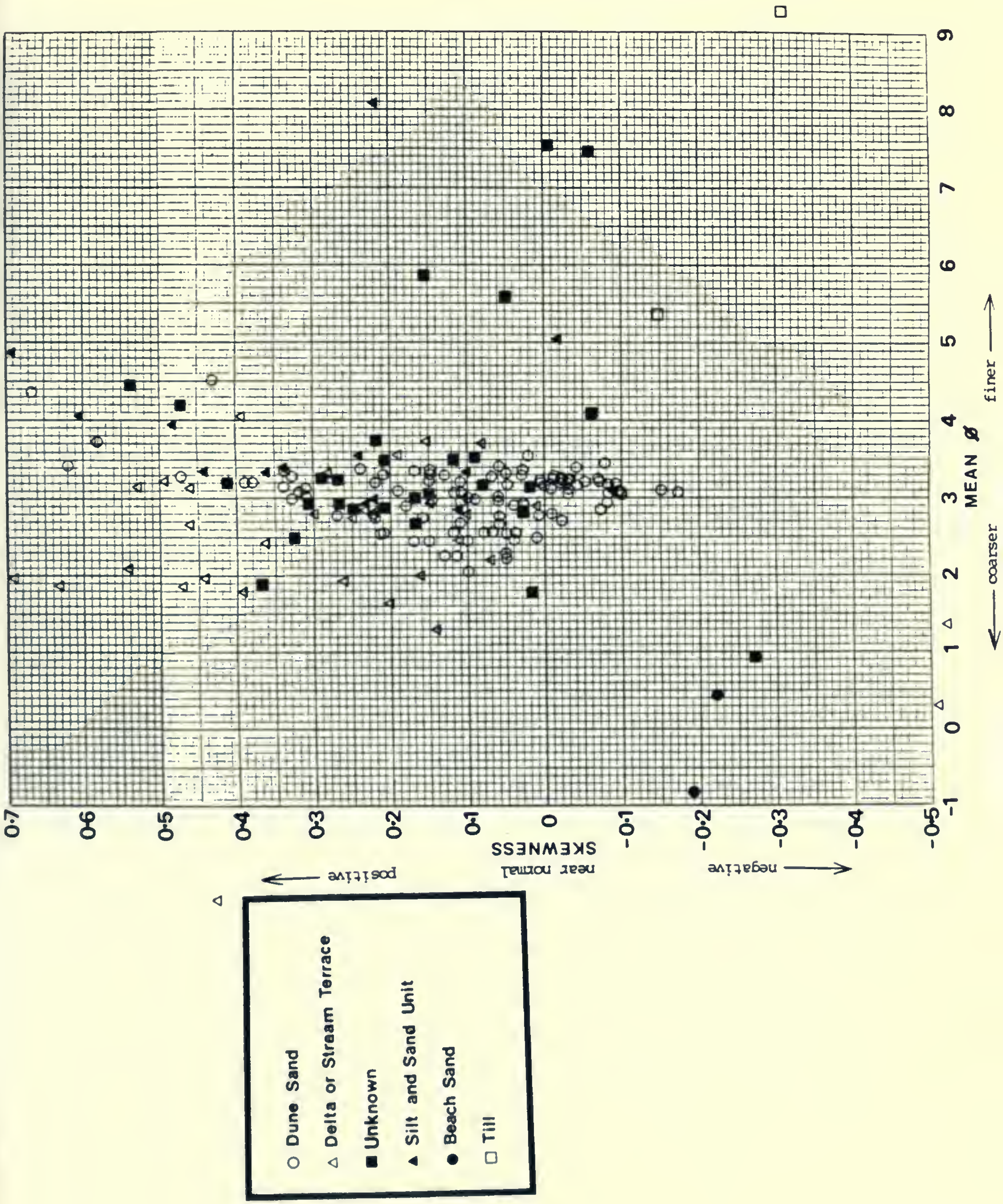


Figure 32: Bivariate Parameter Graph:
Kurtosis vs. Skewness

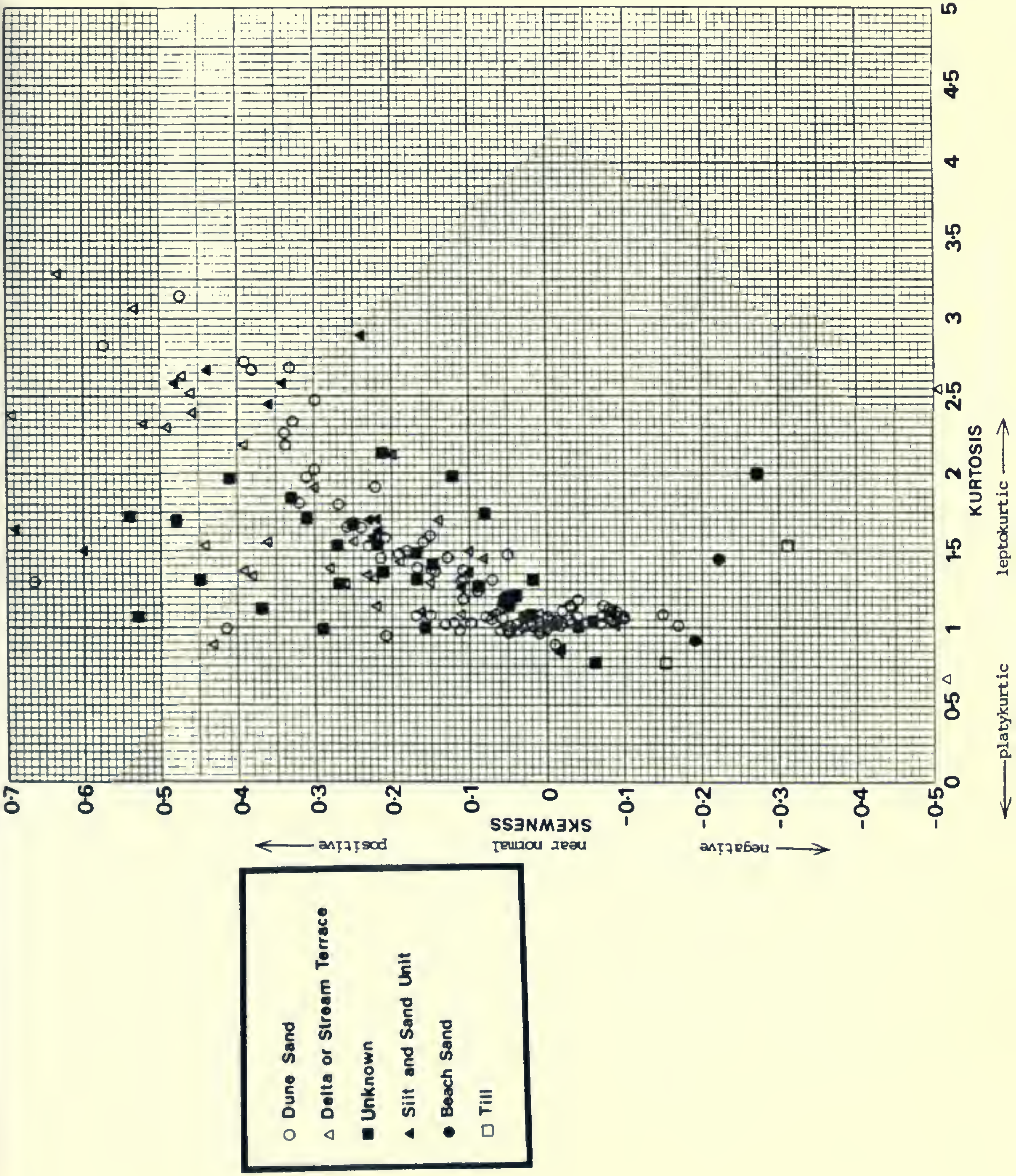


Figure 33: Bivariate Parameter Graph:
Sorting vs. Skewness

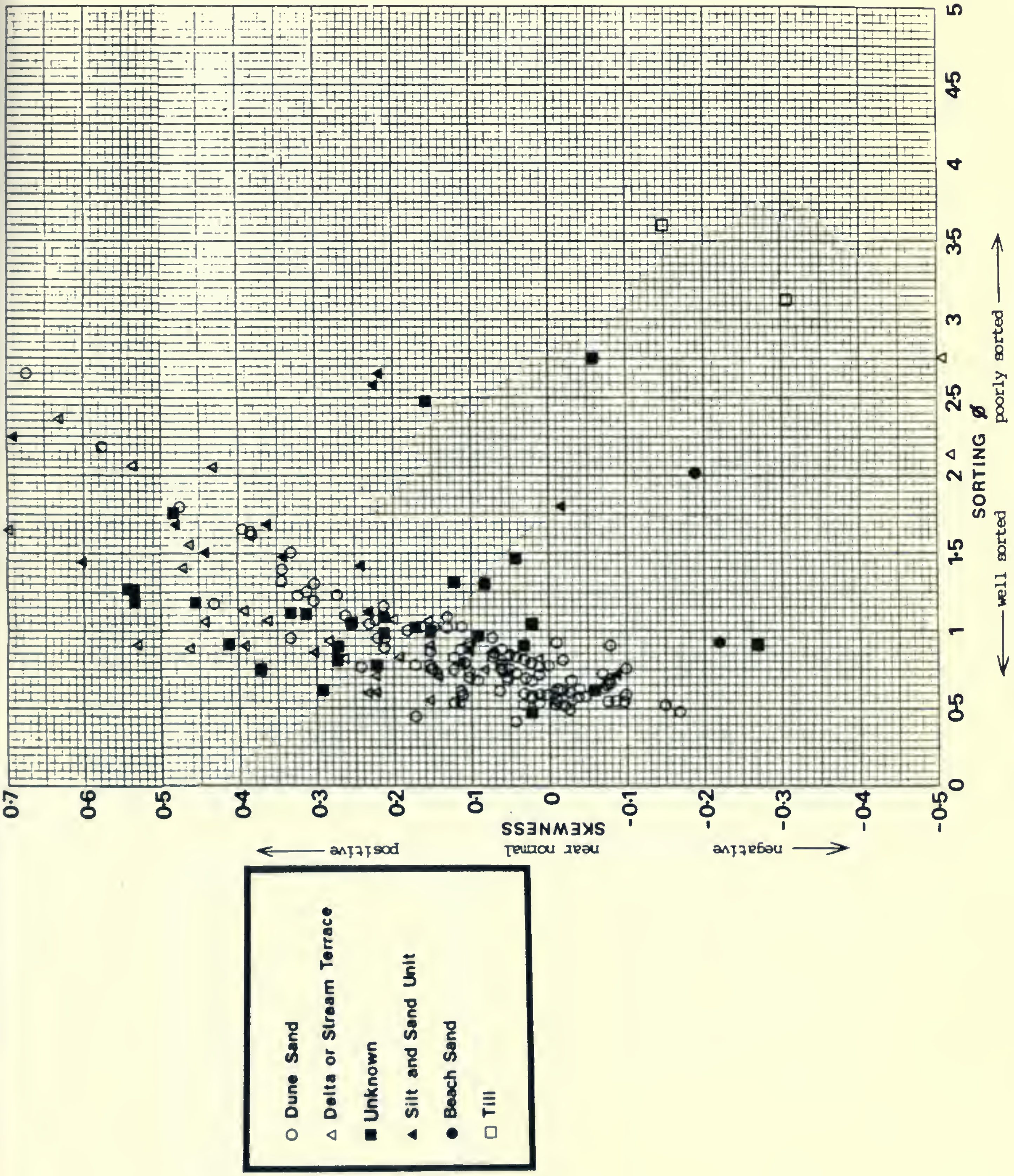


Figure 34: Bivariate Parameter Graph:
Mean vs. Sorting

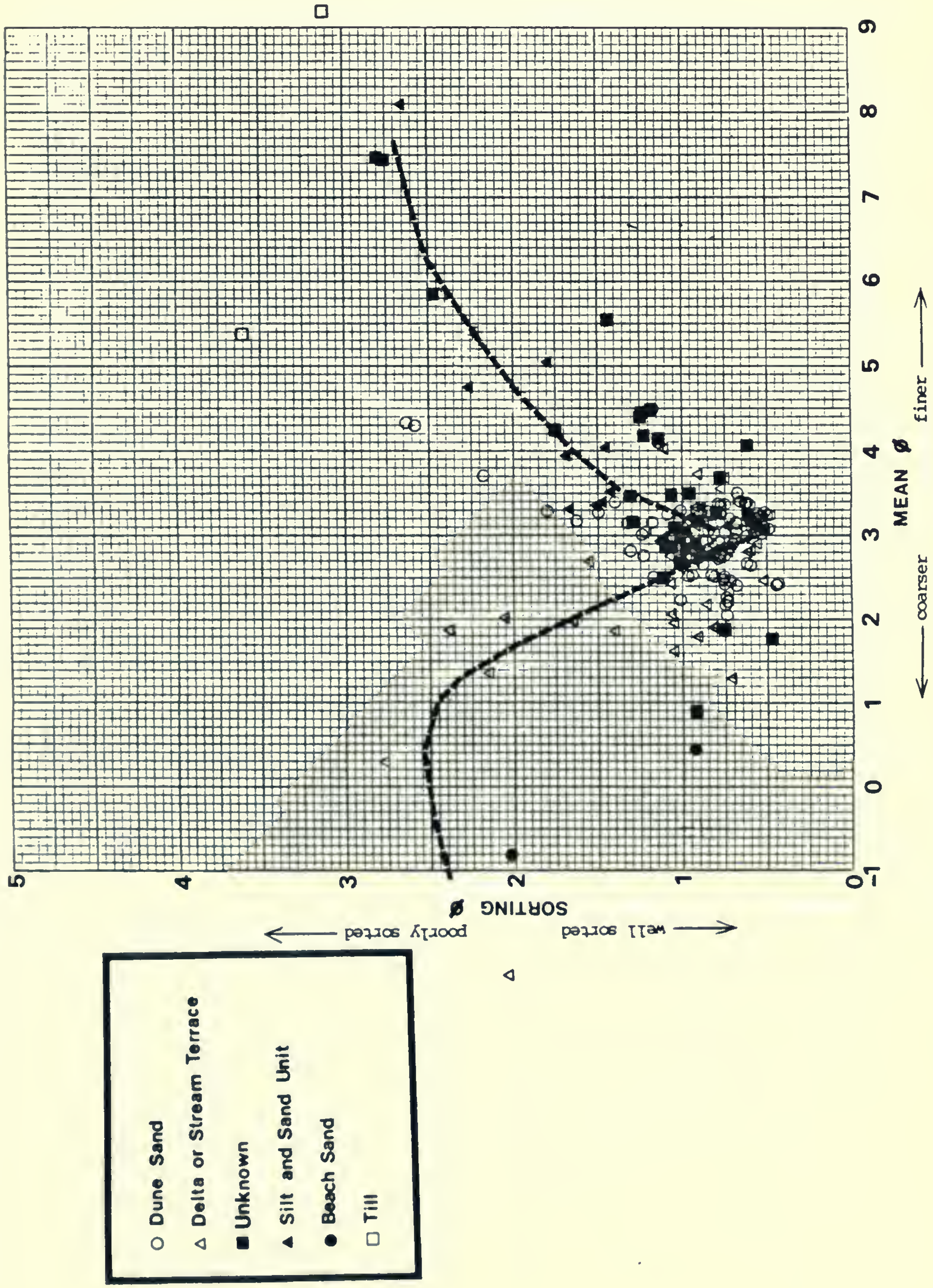


Figure 35: Bivariate Parameter Graph:
Mean vs. Kurtosis

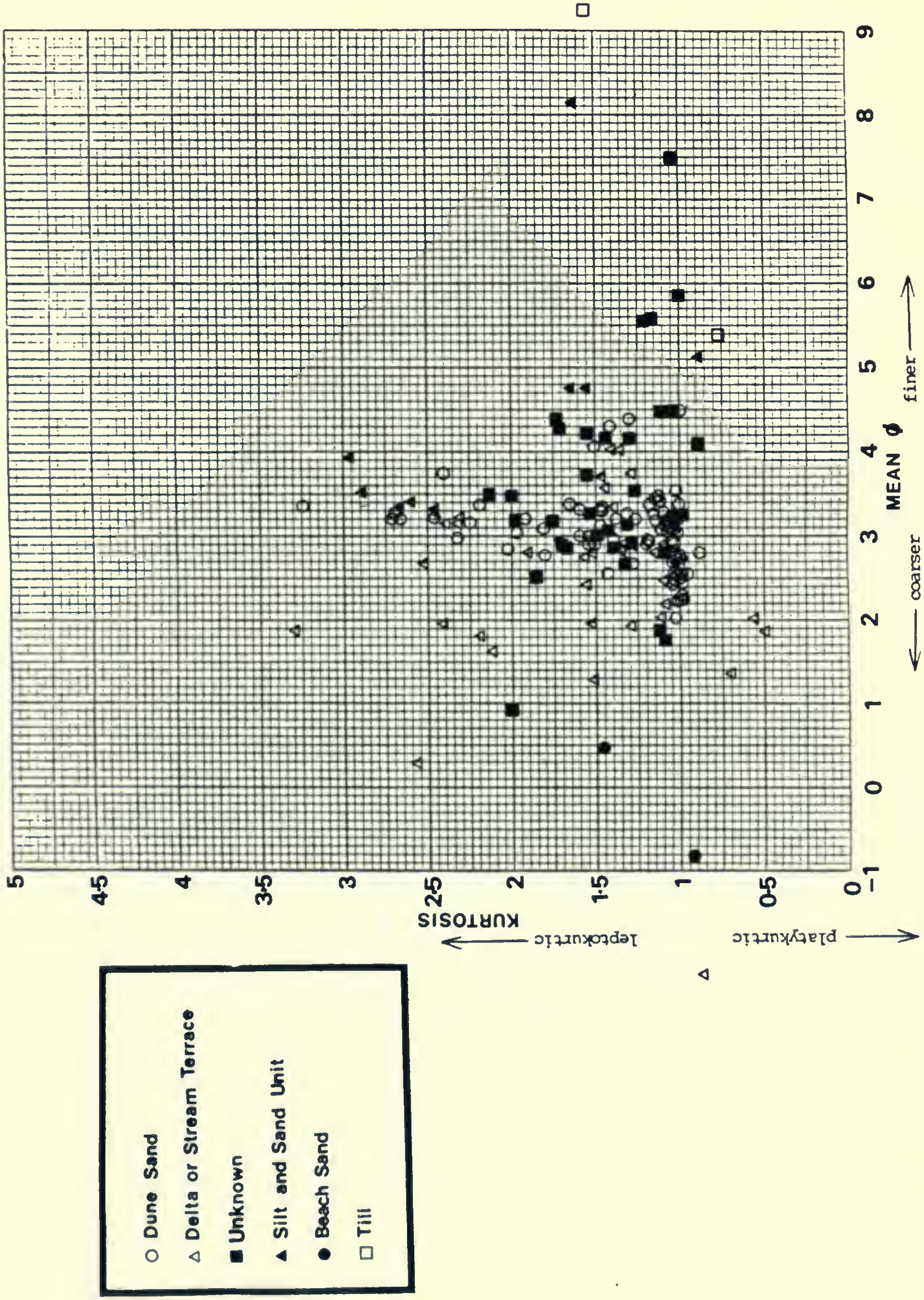
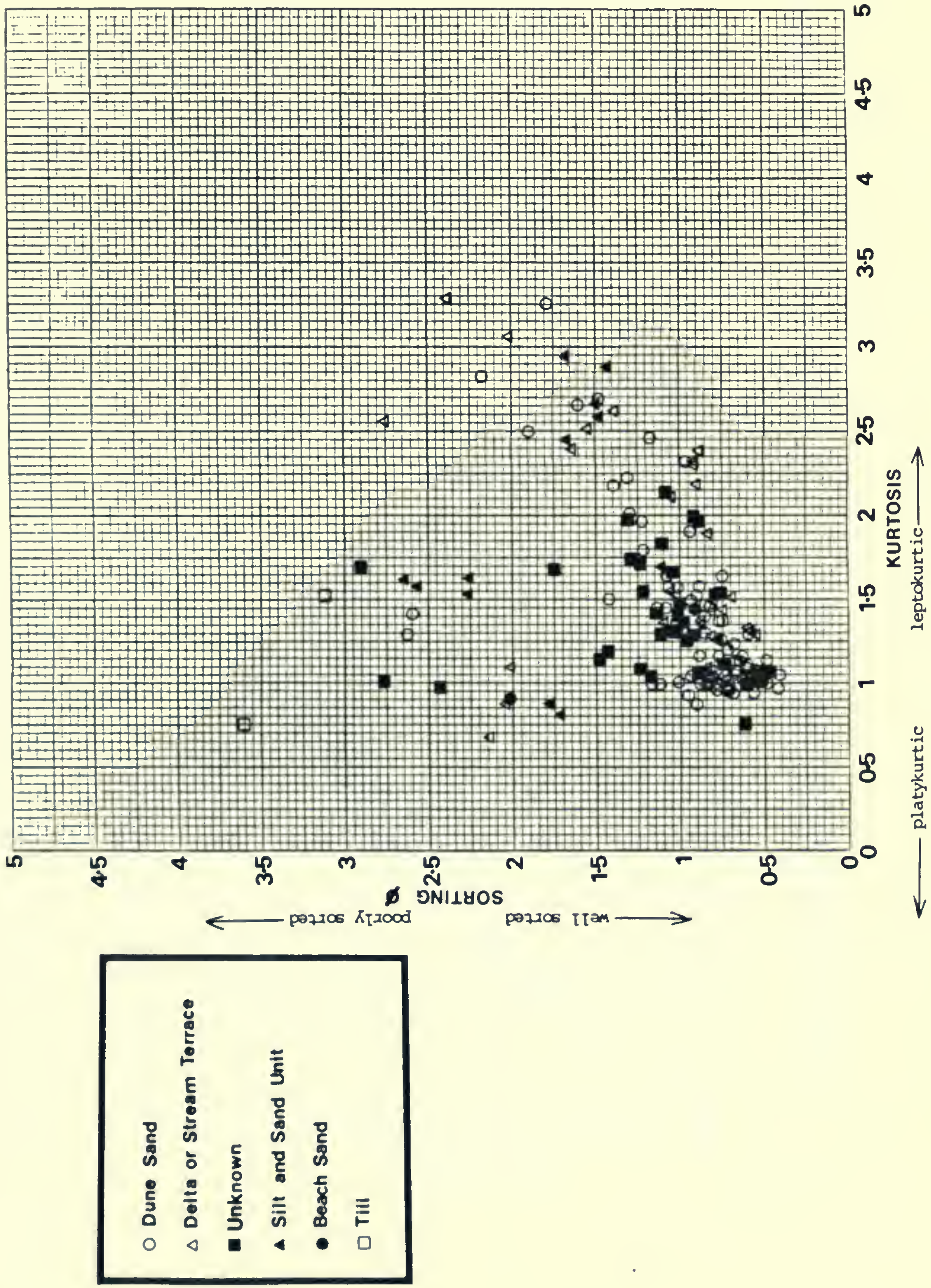


Figure 36: Bivariate Parameter Graph:
Kurtosis vs. Sorting



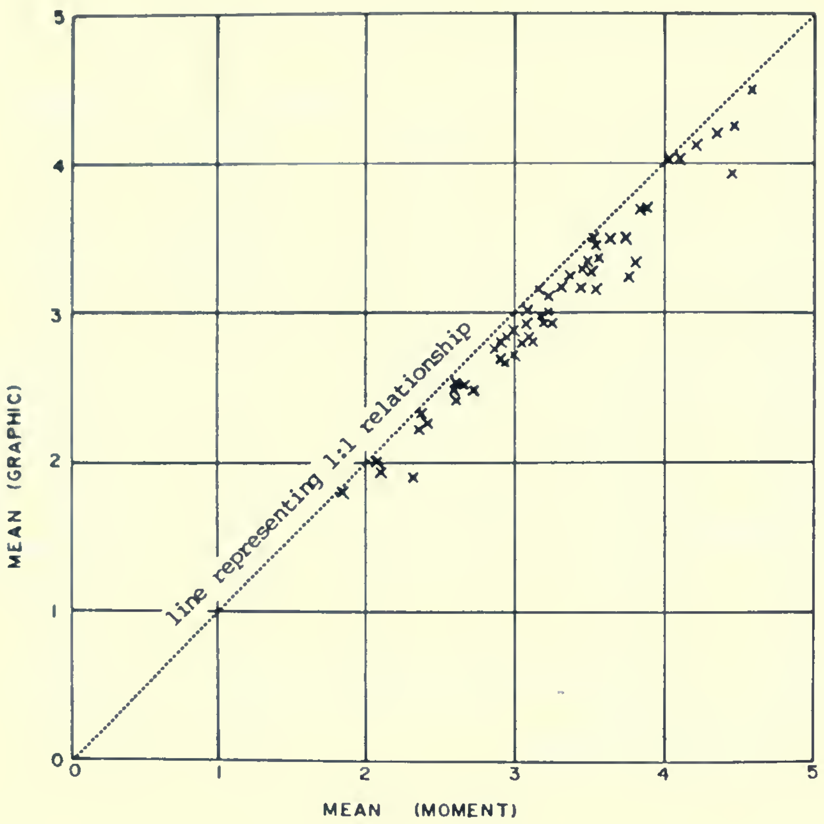


Figure 37: Moment Mean vs. Graphic Mean

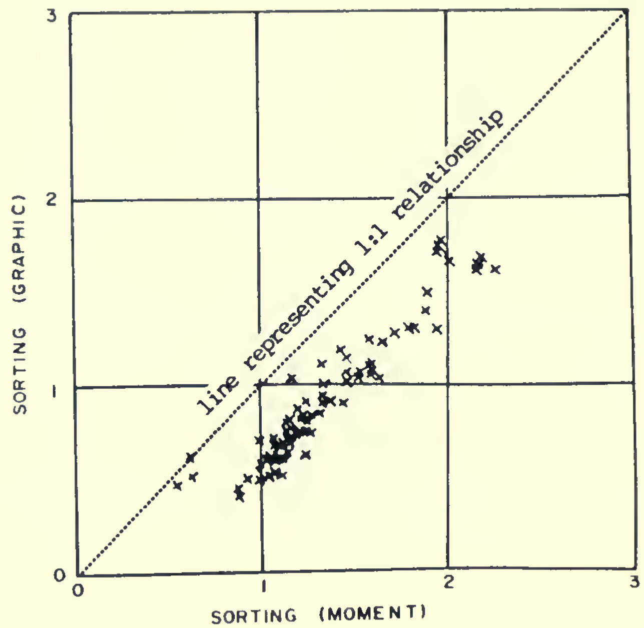


Figure 38: Moment Sorting vs. Graphic Sorting

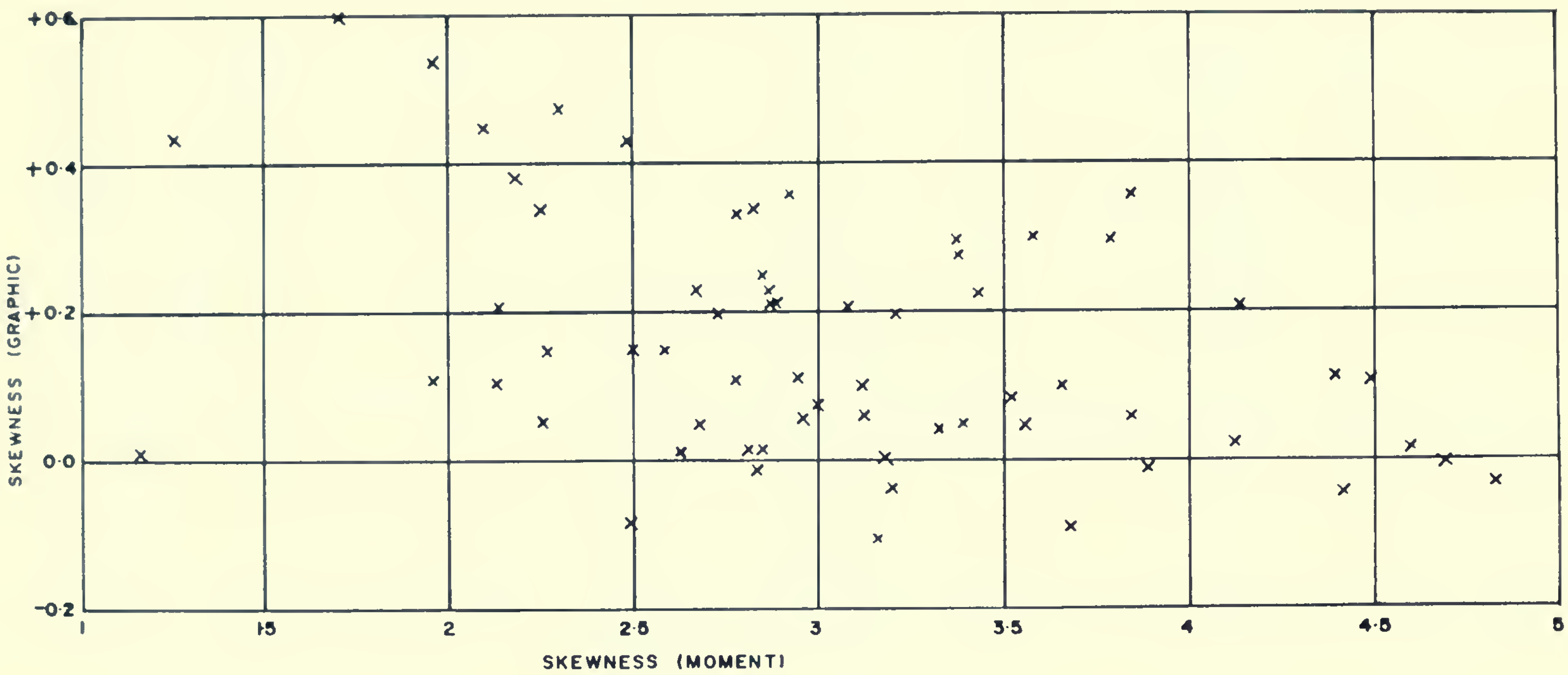


Figure 39: Moment Skewness vs. Graphic Skewness

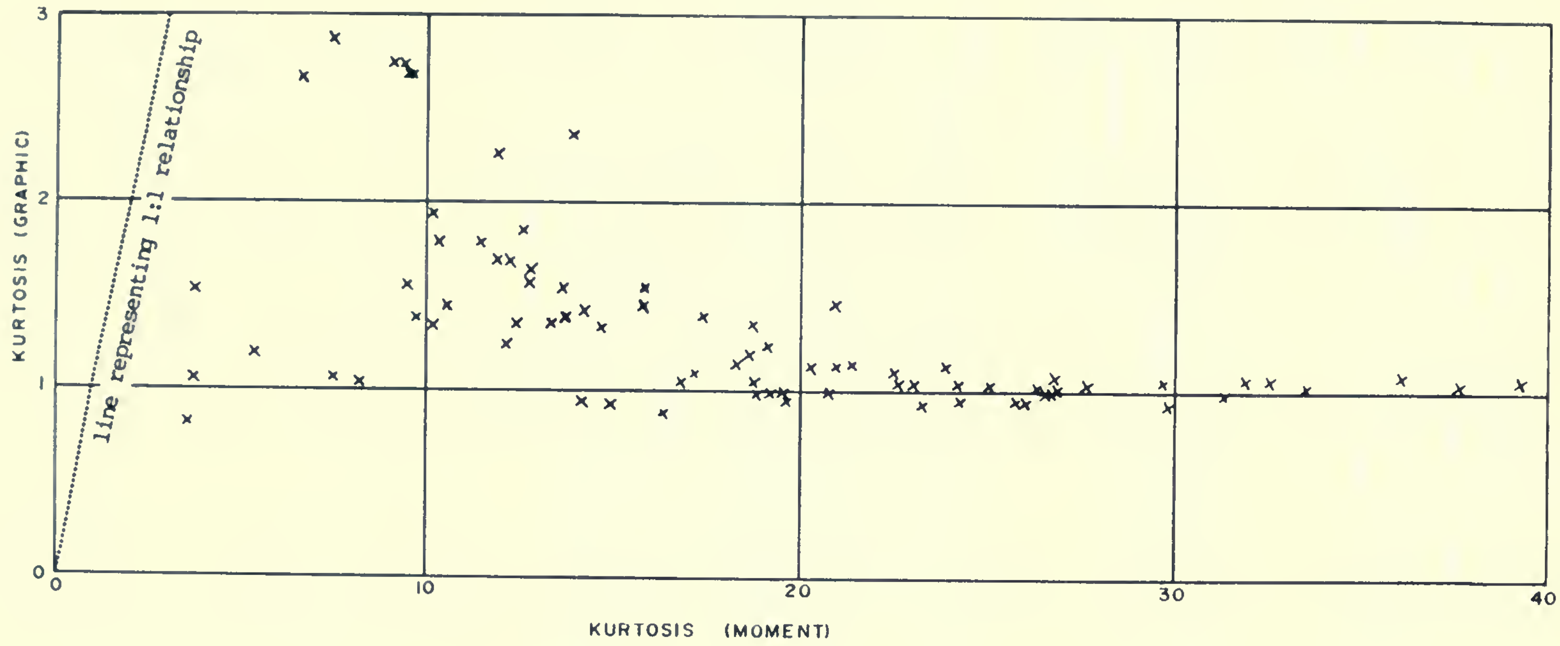


Figure 40: Moment Kurtosis vs. Graphic Kurtosis

CORE PEEL PHOTOGRAPHS AND X-RADIOGRAPHY

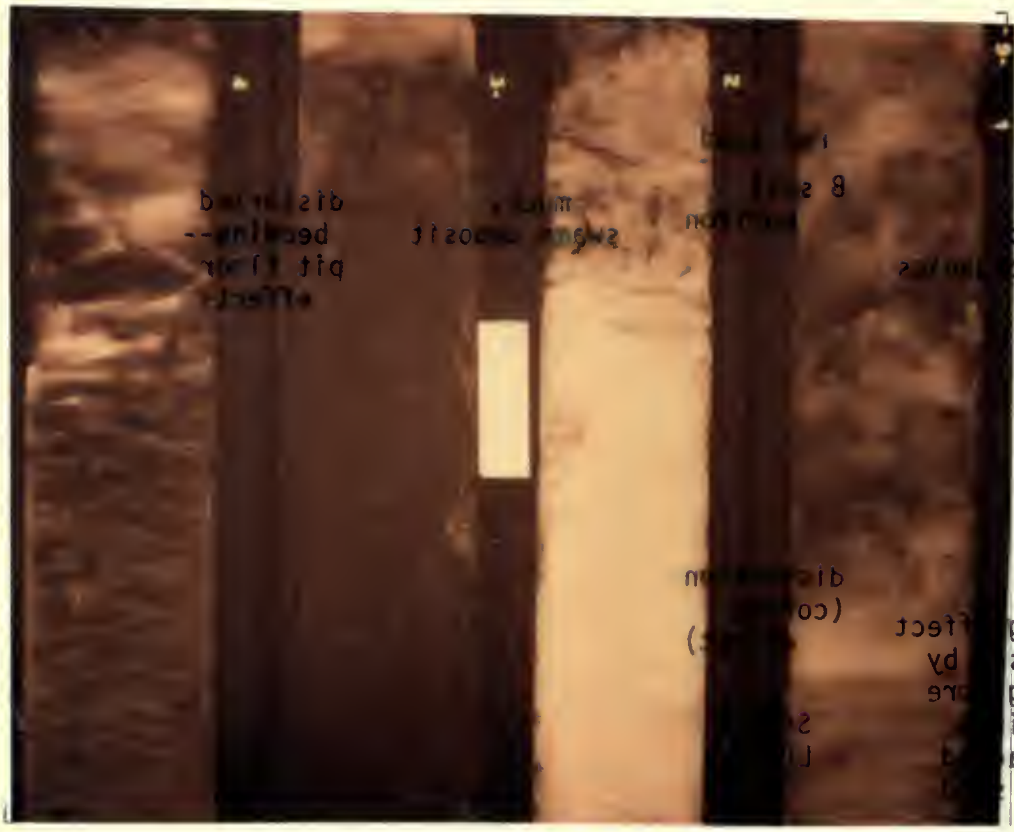
The plates on the following pages are included as a complement to Enclosure 1. All core peels were photographed and X-rayed for examination purposes, but not all core peel imagery is included here. Sets of core peel imagery not displaying sufficient structure were not reproduced. For detailed descriptions of all cores, see Enclosure 1.

It should be noted that because of the overlapping colour photography, sections of X-radiographs (usually the "A" plate of the lower set) occasionally will not match well with the corresponding colour photograph.

On the colour photographs, the vertical scale is in centimetres, and the core peel identification is precisely the same as the right-left sequence of the X-radiographs facing them. In terms of the X-radiographs, there is a lead bar (showing as a white rectangle) on each one. This is a 6 centimetre scale. Film edge effects required the gap seen between A and B pairs of X-radiographs on each page. A light image on the X-radiographs represents a thick portion of the peel, and is usually, though not always, indicative of coarse material. Conversely, dark sections signify areas more transparent to X-rays.

LC1 LC2 LC3 LC4

PLATE 5A



LC4 LC3 LC2 LC1

horizontal

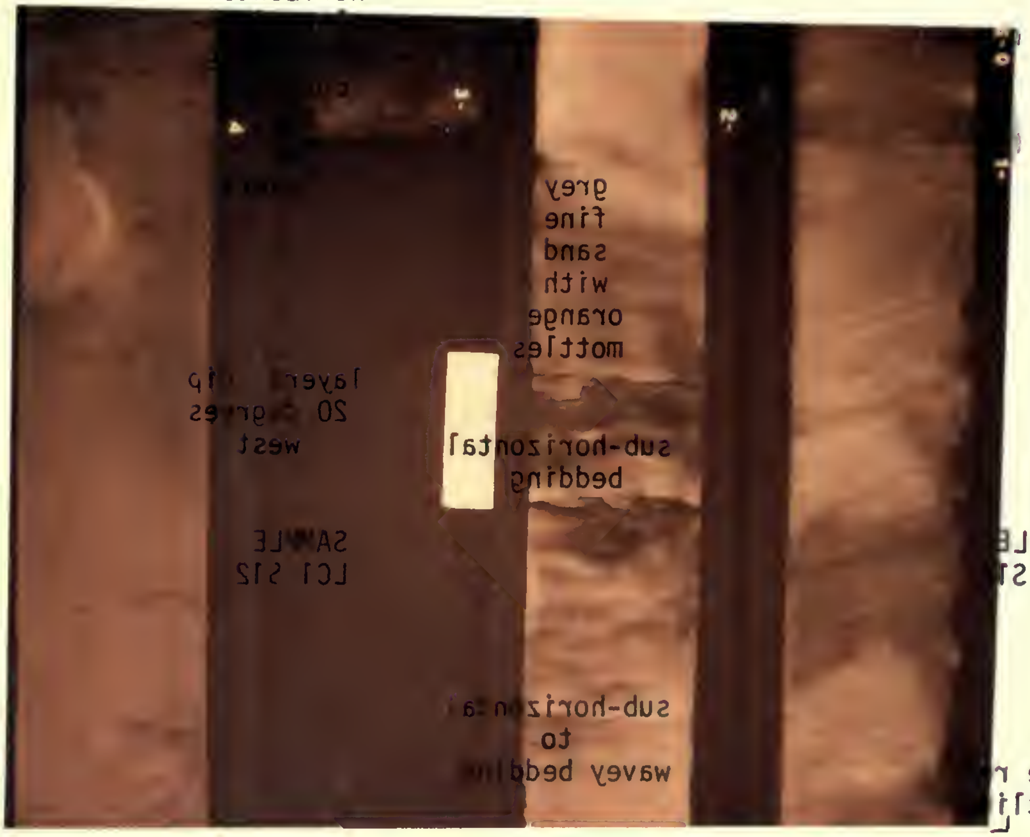


PLATE 5B

Jenny Jump
Pit Floor
DUNE

Gerry's Dune
SILTY SAND APRON
UPPER SET

Gerry's Dune
DUNE

Gerry's Dune
DUNE

Facing Page is PLATE 5C


LC 4
W E
AS VIEWED
LC2
ORIENT-
ATION
L.C.#1
W. E
AS VIEWED
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75

PLATE 6A

LC4 LC3 LC2 LC1

PLATE 6B

LOWER SET

Facing page is PLATE 6C

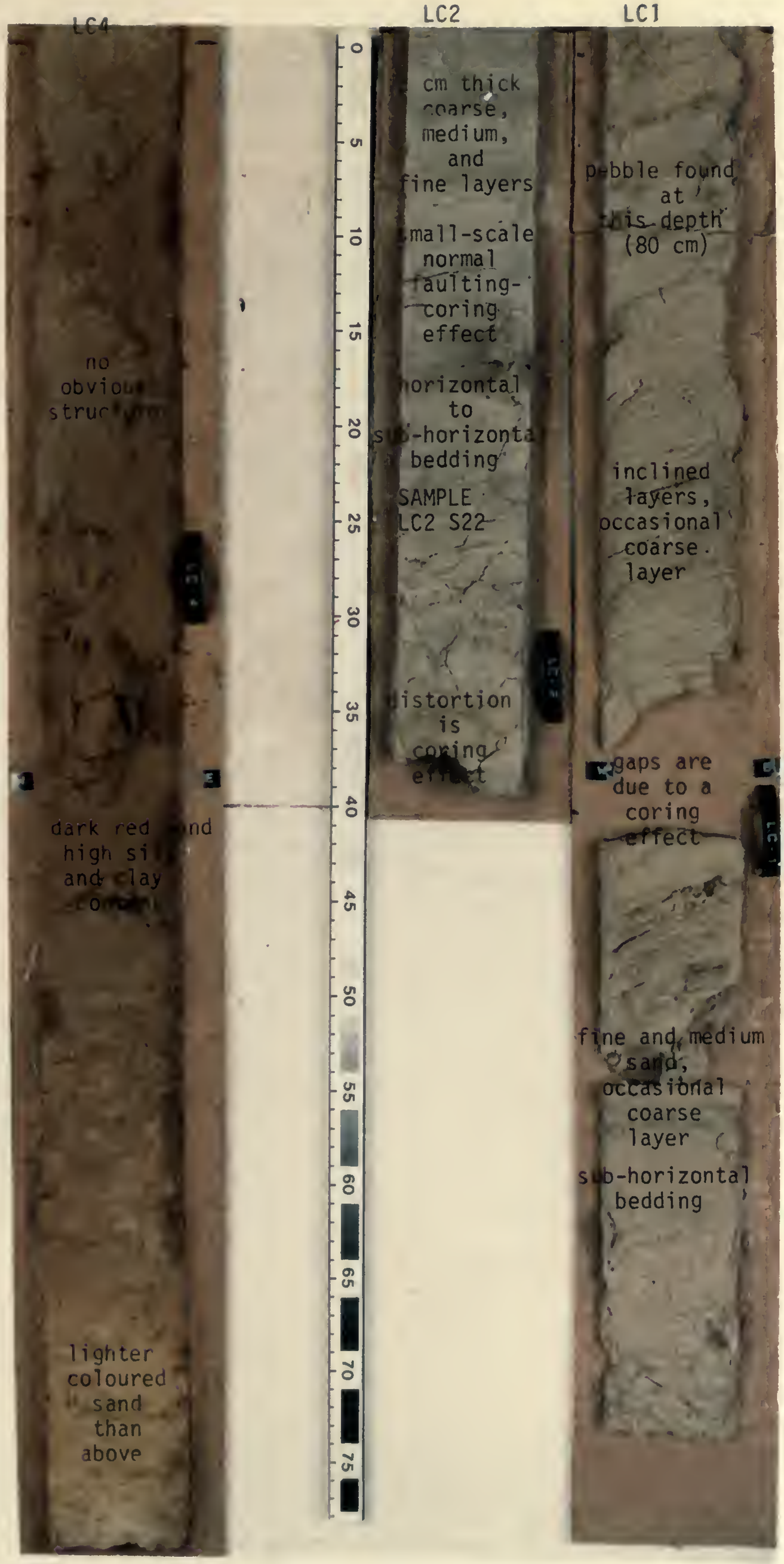
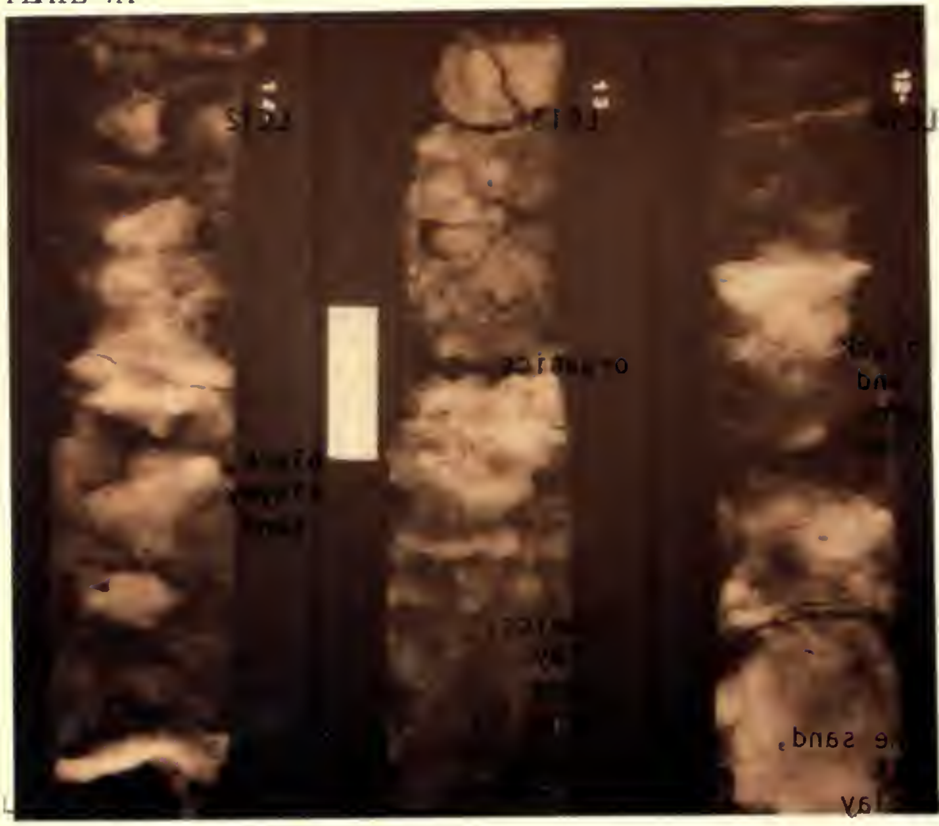

LC4
LC2
LC1
cm thick coarse, medium, and fine layers
mall-scale normal faulting-coring effect
horizontal to sub-horizontal bedding
SAMPLE LC2 S22
istortion is coring
pebble found at this depth (80 cm)
inclined layers, occasional coarse layer
gaps are due to a coring effect
fine and medium sand, occasional coarse layer
sub-horizontal bedding
no obviou
dark red
high si
and clay
lighter coloured sand than above

PLATE 7A



LC14 LC13 LC12

PLATE 7B

Facing page is PLATE 7C


LC 14
LC 13
NO ORIENTATION
LC 12
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75

PLATE 8A

LC14 LC13 LC12

PLATE 8B

LOWER SET

Facing page is PLATE 8C


LC14
LC13
LC12
grey clay
laminated silt and clay
very fine sand and silt
pinkish-grey, medium to coarse sand wavey bedding
SAMPLE LC13 S20
medium sand, slight orange mottling, fine horizontal lamination
very fine clayey sand
clay
fine and medium sand with clay interbeds
SAMPLE LC12 S19
massive clay
LC-12
LC-13

PLATE 9A

LC26 LC25 LC24

PLATE 9B

UPPER SET

Facing page is PLATE 9C

LC26 LC25 LC24

PLATE 10A

LC26 LC25 LC24

PLATE 10B

LOWER SET

Facing page is PLATE 10C


LC25
LC24
gap--
oring effect
ine tan san
SAMPLE
LC25 S16
horizontal
bedding
coarse
and
tan
orizontall
bedded
coarse san
SAMPLE
LC24 S13
orizontall
bedded
coarse sa
SAMPLE
LC24 S15
ilt layers
ine sand
ilty clay
SAMPLE
LC24 S23
ty grey sa
LC-24
0
5
10
15
20
25
30
35
40
45
50
55
60
65

PLATE 11A

LC32 LC31 LC30

PLATE 11B

UPPER SET

Facing page is PLATE 11C

LC32 LC31 LC30

's Y High | Hendor Hot Rd. | Bird Rd. Ditch Cut
DELTA--SILTY SAND BOUNDARY | DELTA UNIT | DELTA UNIT

INTERPRETATION AND DISCUSSION

INTRODUCTION

The landscape of the thesis area is generally flat, but very gently undulating. This surface is occasionally broken by small knolls and broad, usually low swells. In a few places, these swells can reach a maximum of 5 or 6 metres high and from 50 to 400 metres across. These are the aeolian dunes, some of which are parabolic and examples of which can be seen in Plate 1. In a case like Cemetery Dune, which is a longitudinal dune, the "swell" forms a linear ridge up to 3 km long.

The physiography does not seem to change as one goes from the coarser deltaic sediments in and around the townsite of Dunnville to the area of the silty/sand apron (Feenstra's Unit #3b (1972) and #8 (1974), Enclosures 3 and 4 of this thesis), although this may only be a masking effect caused by the urban buildup in Dunnville. No distinct feature appears to delineate Feenstra's (1974) units 8 and 9. The transition from the deltaic sediments to the silty/sand apron sediments is so subtle, that close examination of sediments on either side was necessary to establish the idea that a boundary had, in fact, been crossed.

No attempt was made to re-map the area, the author having considered Feenstra's preliminary maps (Feenstra 1972 and 1974, Enclosures 3 and 4), to be adequate for his field work. Mapping discrepancies were noted, however, including the failure of the Dunnville sheet unit #8 to match up with the Welland sheet unit #3b. This discrepancy has been accounted for on Enclosure 2. Occasionally, in the field, dunes could be found where none existed according to Feenstra's maps. A mapping style change is also quite evident between the Dunnville and the Welland map sheets, particularly in the mapping of the dunes. Also, some dunes reported on Feenstra's maps could not be found at all.

In general, air photographs were not entirely useful in locating dunes that could be candidates for sampling in detail. They were, to a certain extent, useful in the field for locating the position of the field party, and suggesting certain paths to follow to reach desired destinations. Field investigations reveal that some of the parabolic patterns seen on airphotos are the scars left after a dune has been removed as an aggregate supply.

Drainage:

The high water table was quite evident in the ponds and swampy areas that were observed when visiting the sand pits of the thesis area. The high water table is not unexpected, as the area is very flat, underlain by glaciolacustrine clay and silt, within approximately 5 metres of the mean elevation of Lake Erie, and receives a mean annual precipitation of 82 to 88 centimetres. The straight, man-made ditches, constructed in an attempt to drain the area, stand out against the mostly dendritic patterns formed in the surrounding surficial sediments. (Enclosure 5) There were, in fact, no natural drainage systems (ie. creeks or streams) seen within the Dunnville delta and the silty/sand apron during field work.

Many farmers in the area have installed drainage tiles made of fired clay or other materials in an attempt to improve drainage. The desired result of installing drainage tiles is dependent on the discharge of collected water into ditches. The effect of the tiles on the water content of soils during extremely "high water" may be marginal or perhaps negative, since the tiles may provide a conduit for water from the drainage ditch into the soil.

The poor drainage of the area has had an effect on the post-depositional changes in the sediment. These are discussed in the section on soil effects.

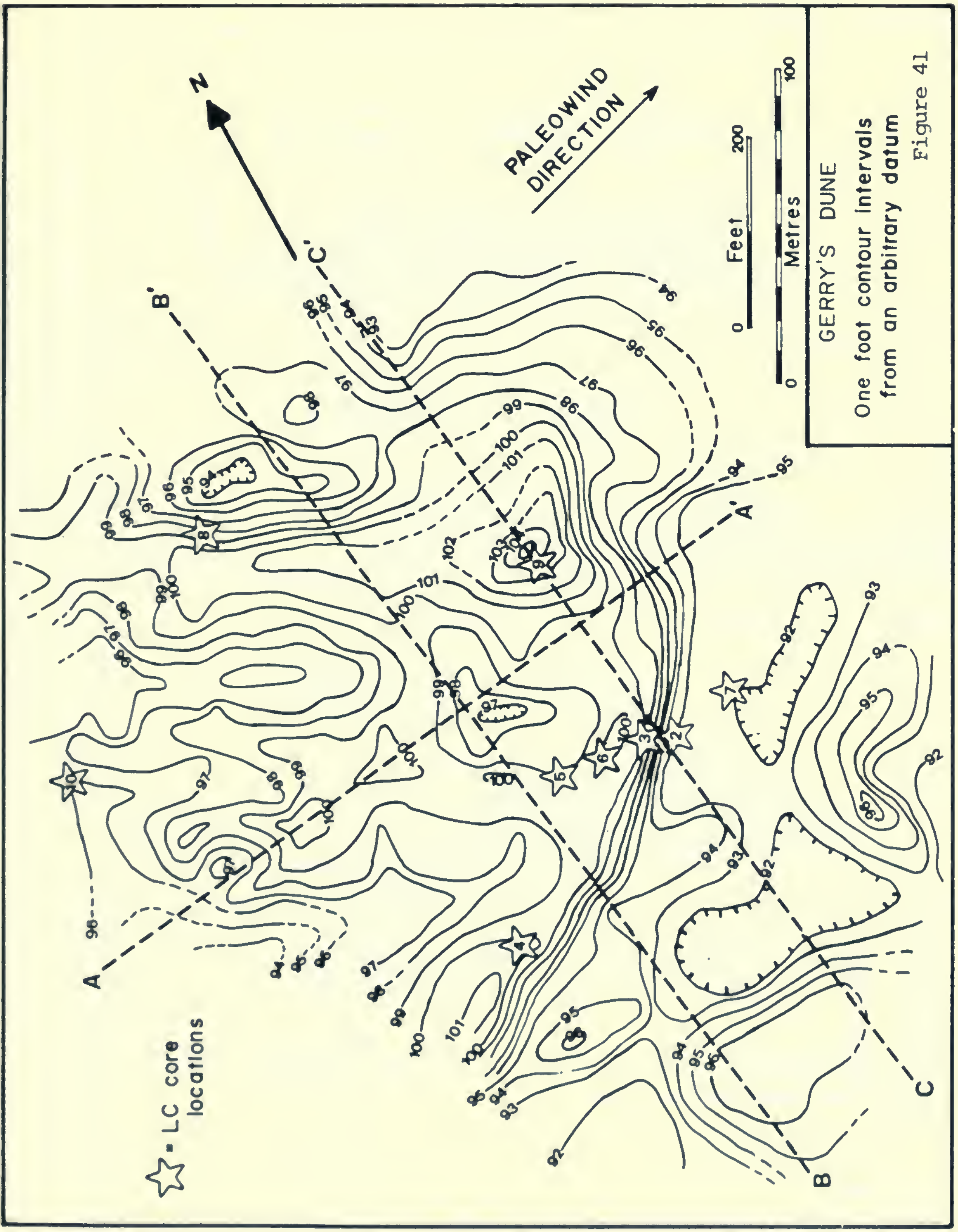
Age Dating

The age of 225± 100 years for the peat block found in Dunnville indicates that the material was buried in the recent past. Perhaps it was buried at a time when early settlers attempted to improve the condition of the poorly drained area by draining ponds and bogs and/or filling in the low areas, a process still used in the area to this day.

In another attempt to obtain an in-situ sample of organic material for age dating, a core was obtained approximately 30 m away from the site where the sandy peat block was discovered. This core, LC29, reached a depth of 1.27 m and bottomed in compact pink and grey clay without encountering organic material at depth (See Core Descriptions, Enclosure 1). However, from the surface to a depth of 48 cm, a black, organic muck containing many roots and a gastropod shell was seen. This is considered to be in-situ swamp material at the surface. Within 5 m of the coring station, approximately 0.5 m of fill was observed to cover these swamp deposit(s). It appears that this is evidence for the conclusion that Barnett's peat and/or shell samples are of a "modern" age, even though there is no observable physical connection between the various peaty deposits.

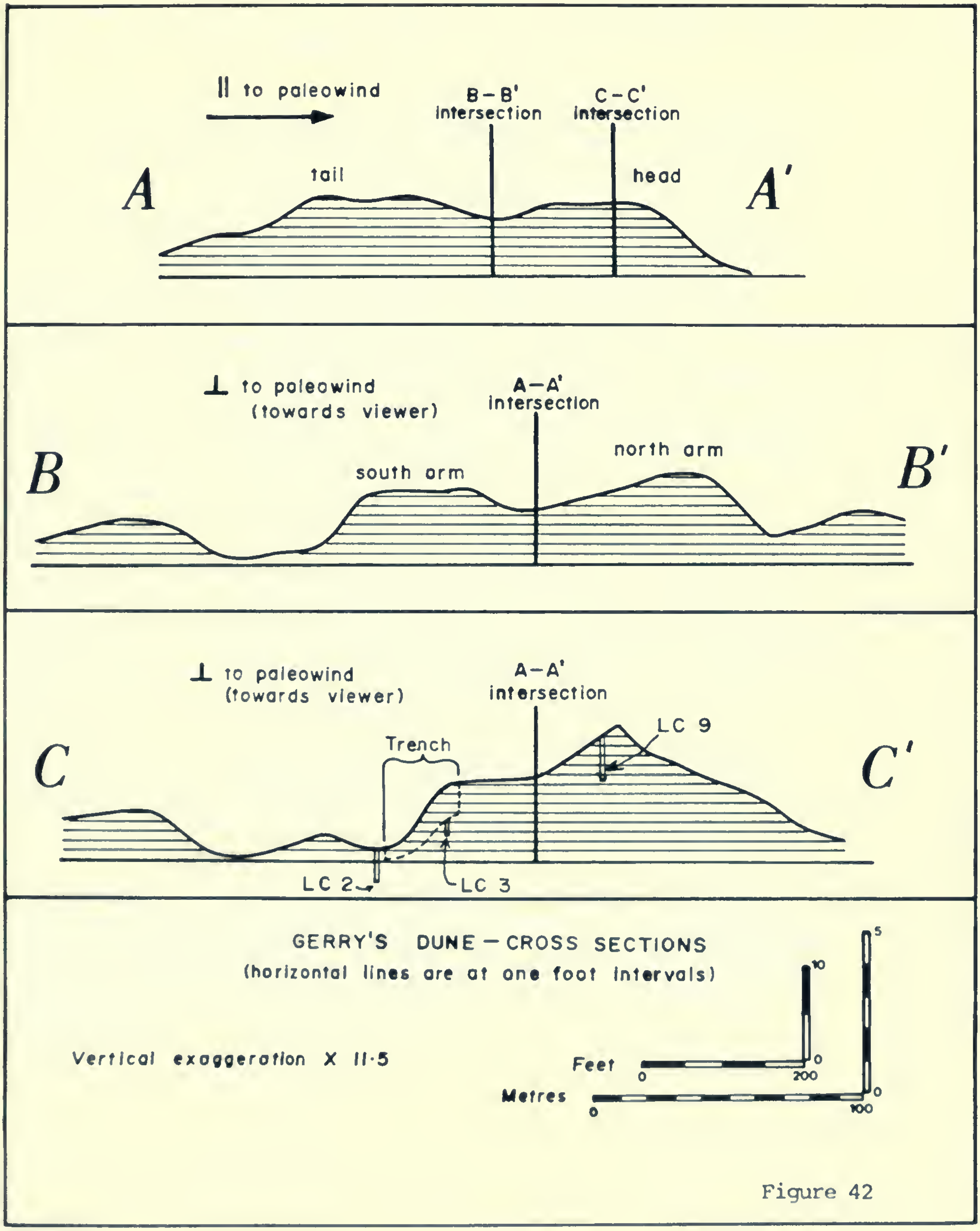
Maturity of the Dunes

Field surveying produced the detailed topographic map shown in Figure 41. This figure shows the general parabolic outline of Gerry's dune, while Figure 42 illustrates generalized cross-sections, both parallel and perpendicular to paleowind direction. These cross-sections display the apparently poorly-developed dune morphology common to many of the smaller, low amplitude dunes in the thesis area. For example, section A-A' exhibits very little gradient between the "upwind" tail and the "downwind" head, as may be expected from comparisons with examples from worldwide desert dunes (Spearing, 1971; McKee, 1966). (Note: Figures 41 and 42 are contoured in Imperial measurements because the instruments used to survey the area were calibrated in Imperial increments. The one foot intervals also allowed for sufficiently detailed topographic expression).



GERRY'S DUNE
One foot contour intervals from an arbitrary datum

Figure 41



GERRY'S DUNE — CROSS SECTIONS
(horizontal lines are at one foot intervals)

Figure 42

This poorly-developed morphology is evidence that most of the dunes were not active for a long length of time, and that, for the most part, their growth seems to have been "arrested" before they achieved large, mature forms.

In terms of the mineralogy of the sand, the presence of soft rock particles (carbonates, gypsum) with quartz, and the angularity of most of the quartz grains indicates that transportation and reworking effects have been minimal. Otherwise, the softer particles would have been abraded, and the mineralogy would be more mature (ie. richer in quartz). This is another piece of evidence that these dune forms were not active for long periods of time, nor did the sediments move very far before being deposited. It is thus assumed that the material of the dune sands was derived from a very localized source, probably an area of the silty/sand apron directly upwind of each dune.

Very well-rounded and frosted quartz grains are often cited as evidence of an aeolian depositional environment. Although such grains were occasionally seen when examining samples of Dunnville dune sand, their rarity and association with angular quartz grains show that they are not diagnostic of this particular aeolian environment. They were probably derived from an upstream (or up-ice) rock or unconsolidated sediment source of the ancient Grand River (and/or glacial ice). Seppala (1969) states:

"According to Cailleux (1942, p. 109), the sand must be under the influence of recurrent aeolian processes for a very long time before the greater part of the grains are formed into ballshaped ones. Kuenen (1960) thinks that the complete rounding of quartz grains requires that they are carried by wind for hundreds of kilometres".

Soil Effects:

Most of the chemical changes between weathered and unweathered material can be linked to the dissolution of carbonate particles within the soil. The red, weathered material has had most of its carbonate particles dissolved, resulting in a decrease of its CaO value (13.13 to 2.90 wt%) and a corresponding rise in the SiO_2 value. Therefore, once the carbonate materials were removed from the soil by leaching, the remaining material was proportionately enriched in stable minerals (ie. quartz). As this effect is quite large in these samples, other increases or decreases should be regarded with caution, as changes could be masked. For example, the TFe_2O_3 (total iron oxides) and Al_2O_3 values for the PD 16, 17 and 18 series (Appendix IX) appear to increase in the reddish material. During soil formation, iron and aluminum are carried to the "B" horizon as hydrates of iron oxide and colloidal clay. The changes in Fe and Al content noted in these samples are significant in terms of the accuracy limits outlined in Appendix IX, but one has to consider that the true amount of iron and aluminum oxides may be the same in all these samples, but the proportion of these oxides to the rest of the sample components may have increased because of the removal of carbonate products.

Pye (1983) in his work on early post-depositional modification of aeolian material, describes what he terms "infiltration structures" as:

"Thin, dark, often discontinuous wavy bands which result from the concentration of vertically infiltrated fine material (ie. silt and clay). Deposition of infiltrated fine material often occurs preferentially along primary fine grain size laminae or along secondary dissipation structures such as shear planes associated with slumps and sand flows. In some cases, however, contorted silt and clay-rich laminae bear little or no relationship to either original bedding laminae or secondary deformational structures".

Pye also suggests that these features may be due to the deposition of fines at the irregular boundary between seasonally frozen and unfrozen sands, or it may be related to the limit of penetration of the wetting front after a heavy rainfall. Once fines have been deposited at a particular level, the reduced permeability will tend to favour further accumulation at that site and perhaps preferential cementation by iron oxides or other minerals.

The formation of chalky, calcium carbonate "root casts" (or rhizoconcretions), a form of calcrete, around dead and decaying root systems, produced annoying problems when sampling and sieving (Plate 2). If a root cast was encountered during sampling, the sample was usually discarded. This occurred because the root cast would tend to break up into fragile crumbs up to 10 mm in diameter. These crumbs, if sieved along with the rest of the sample, disintegrate further, distributing fragmented pieces of the root cast throughout the sieving stack, making the grain size distribution meaningless. It was thought that this contaminating material could be removed by washing the sample in HCl, but the root cast could not be dissolved without affecting the abundant sand-sized particles of limestone and dolomite present in all of the samples.

Calcrete (including the rhizoconcretions found in the thesis area)is non-pedogenic. It is forming at depth well below the modern soil profile. An important feature of calcrete is its close association with vegetation. Plants utilize vadose and phreatic waters causing precipitation of $CaCO_3$, and play a significant role in the structural development of calcrete. The prevailing view in the literature is that surface waters infiltrate through the vadose zone dissolving $CaCO_3$ and ultimately precipitating calcrete (Semeniuk and Meagher, 1981). In the thesis area, calcrete is precipitating as rhizoconcretions around the root systems of plants. (For further information on the structure and formation of calcrete in its various forms, the reader is directed to the reference cited above, as well as a paper by Cohen (1982).)

Sampling Effects:

The extensive program of sampling at Cemetery Dune has provided data on how different sampling methods can result in varying sample parameter values. Sampling of the individual laminae is useful for showing extremes of grain size parameters (Figures 7 and 8), general trends from bottom to top (Figure 7), and possible evidence of small scale cyclic deposition (Figure 11) Data for spot samples over systematic intervals (regardless of bedding boundaries) tend to approach the mean values of grain size parameters for that exposure. Also, if general trends are fairly evident in exposures, this method of sampling should adequately document them. Channel sampling can result in some misleading conclusions, particularly if sub-unit boundaries are crossed, or an incomplete channel sample is taken over a graded unit. Figures 7, 8 and 9 illustrate the extremes possible when sampling this exposure using different lengths and positions of channel samples.

TERNARY GRAPHS

The ternary graphs of sample textures illustrate the difficulty of establishing the depositional environment of any one sample merely by grain size.

Comparison of all four ternary graphs (Figures 13 to 16) support Feenstra's (1972 and 1974) observation that the dune unit, delta or stream terrace unit and the silty/sand unit are all closely related.

All of the 98 samples identified as being of aeolian dune origin plotted in the "sand" field as defined by Shepard (1954) (That is, greater than 75% sand-sized particles by weight). The data points on Figure 13 include results from multi-sample outcrops (ie. Horse Farm Site, Cemetery Dune) but not results from in-lab accuracy repeat analyses nor "non-freeze dried" samples.

A similar situation exists for the delta or stream terrace samples collected, with 27 out of 31 samples plotting in the "sand" field and 4 plotting in the "silty sand" field. (Figure 14)

Figure 15 shows more of a range among the silty/sand apron textures. The two beach sand samples, (one from Port Maitland and one from Charles Daley Park) that are plotted on this graph have over 99% sand and gravel content. This appears to be a function of their beach-related, high-energy environment that would winnow out most, or all of the fines. (It should be noted that these beach sand samples contained 43.06% and 8.40% gravel, respectively). The two till samples (Halton and Wentworth tills) plotted on Figure 15 are included merely for reference, and should not be interpreted as representative of the two different tills. Figure 22 represents the textural variation found in the samples from unknown environments.

GRAIN SIZE STATISTICS MAPS

These maps (Figures 17 to 23) were generated to illustrate trends across the thesis area, and to try and isolate exceptions to these general trends.

As the source of the sand in the thesis area is the ancient Grand River glaciofluvial system to the west, most trends observed should be from west to east. This would be the result of the high-energy fluvial system discharging into a lower-energy shallow lake. In this situation, the coarsest sand would be deposited nearest the source, where the energy level of the fluvial system would drop rapidly as the water flow entered the lake. Accordingly, Figures 17 and 21 clearly illustrate the trend from coarse, relatively pure sand in the west to finer, "dirty" sand in the east. The most notable exception to this general trend is seen on Figure 17, where four white triangles, representing clean

sands, are located in the east end of the map area, and are surrounded by black symbols representing sand with a relatively higher mud content. These four white triangles represent samples from Gerry's Dune and Cemetery Dune. The higher proportion of sand in these samples seems to indicate a certain amount of winnowing of fine particles. This winnowing effect would have taken place as the sand was reworked by aeolian action.

The Percent Silt and Percent Clay maps (Figures 18 and 19) also show a general trend from clean, coarser sand in the west to dirty, fine sand in the east. However, the trend seen on these maps is less distinct. Figure 18 exhibits the overall dominance of samples with a silt content of less than 15%. Figure 19 shows that the majority of samples contain less than 5% clay. The exceptions are samples on the fringe of the mapped area. These samples, high in fines content, are either from an extreme distal portion of the Dunnville Delta, or were deposited in more of a glaciolacustrine environment. There are some samples near the centre of the map area with a relatively elevated clay content (ie. black symbols). This higher clay content could be the result of translocation or filtering down of clay particles, via groundwater, from the zone of soil forming activity higher in the section.

In some cases at the western edge of the map area, the relatively high clay content of some samples is most likely due to "clay balls" found in the coarser sand unit at Dunnville. These clay balls are similar to those seen in the core photographs, X-radiographs and descriptions of LC31 (Plate 11A-C), and the lower portion of LC32. Clay balls within analyzed samples would not likely be as large as the clay balls shown in those cores.

On Figure 20, it is interesting to note that the east end of the map area has a strong dominance of black symbols (fine sediment), including the samples that plotted as white triangles on Figure 17. This illustrates that, while these dune samples may have had their fines removed by reworking, as indicated by Figures 17 to 19, they still fit the overall fining eastward trend. This

supports the hypothesis that the source for these particular dune sands is immediately local.

The sorting value map (Figure 21) seems to indicate that there is no clear-cut relationship between how well a sediment is sorted and its distance from the major source at Dunnville. There is, however, the very gross relationship that sand samples from large, well formed dunes (ie. samples PD 364, PD 367, PD 369, PD 83, LC23 S17, PD 324, PD 403, and PD 360, etc.) seem to be generally more well sorted than other samples from lower features or areas at the base of large dunes.

There are exceptions to this general observation. For example, sample N-09 is from the sand pits at Kentucky Hill Dune. This sample has a sorting value of 1.16, as compared to the value of 0.52 for sample PD 162, which is from the "Bird Road Excavation Site", and is definitely not a dune deposit. The ripple cross-lamination observed at the site of PD 162 indicates a water-laid deposit associated with the main delta formation at Dunnville.

There appears to be no discernable skewness pattern over the map area, other than the very subtle tendency to have the skewness value approach zero in the east from values between 0.21 to 0.40 in the west. This suggests that the samples further away from the source (the delta at Dunnville) have had their coarse "tail" removed, and are approaching a normal distribution. This indicates that the source of sediments has an "excess" of coarse grained material that is gradually removed by transportation processes.

The kurtosis value of a sediment is a numerical representation of the peakedness or the "flat-toppedness" of the grain-size distribution. A sample with a kurtosis value of 1.00 is considered a normal distribution, while a sample with a value less than 1.00 has a flatter top. Conversely, a sample with a kurtosis value greater than 1.00 has a sharper peak than a normal distribution. Most of the mapped samples have a kurtosis value of greater than 1.00, indicating leptokurtic distribution (white

triangles) or a distribution better sorted in the central part than at the tails. (ie. a distribution with a high central "peak") (Figure 23). Samples with kurtosis values less than 1.00 (white circles) may be indicative of samples tending towards bimodality, or mixing of grain size populations, possibly an effect of channel sampling. There does not seem to be any relationship between kurtosis value and distance from source.

PARAMETER TREND GRAPHS

These graphs (Figures 24 to 30) were generated, along with the statistical analysis of parameter values, to more quantitatively evaluate trends seen on Figures 17 to 23. In these evaluations, no effort is made to isolate deviations from the general trends, except for the five "lake-bottom" samples, indicated by circled data points. In some cases, where values for these five samples are extreme, they drastically alter the position of the "best fit" line, as well as altering the values of the population statistics obtained (ie. N=67 data (dashed line) as opposed to N=62 data (solid line)). The most extreme cases are illustrated on Figures 24 and 25, where the slopes of the two inclined lines differ significantly.

In order to facilitate meaningful comparisons between the seven graphs (Figures 24 to 30), only data pertaining to samples from the Dunnville delta/aeolian system (ie. N=62 data and the solid inclined line) will be considered henceforth.

Although none of the parameter trends plotted on these figures has an excellent relation with distance from source, some fair to good relations are indicated by the absolute values of correlation coefficients (ie. 0.5165 for Figure 24, 0.5620 for Figure 25 and 0.7280 for Figure 27). Note that these three figures deal with the parameters % Sand, % Silt and Mean Ø values, while the graphs representing % Clay, Sorting, Skewness and Kurtosis values have only fair to poor indications of a direct relation between distance from source and value of parameter. (That is, these graphs have absolute values of correlation coefficients of only 0.3135 to 0.0591.)

This is compatable with observations noted from the grain size statistics maps (Figures 17 to 23) in that the maps dealing with % Sand, % Silt and Mean Ø values produced the clearest west-east trends, while the other maps produced few, if any visible general trends.

Another measure of how well the parameter values fit a hypothesized trend is to examine the population standard deviation value. However, this value is only directly comparable between graphs whose parameter values are in identical units. Therefore, the only graphs that can be considered for comparisons are the graphs of % Sand, % Silt and % Clay. In considering these graphs (Figures 24 to 26), it can be seen that the % Clay graph has the smallest population standard deviation value (1.753). This is a function of the fact that almost all the samples had clay values of less than 10%. However, with a correlation coefficient of only 0.2534, it is not likely that this graph would be chosen as the best example documenting a regional grain size trend. Either the % Sand or % Silt graph would be a better choice, as even though their population standard deviations are greater (6.098 and 5.131 respectively), the absolute value of their correlation coefficients show a much better relationship between these two parameters and distance from source.

Although these parameter trend graphs and the associated population statistics illustrate less detail than the grain size statistics maps, they are very useful for mathematically confirming what may be subjective observations of trends across the thesis area, such as those seen in Figures 17 to 23, and described on pages 105 to 108.

BIVARIATE PARAMETER GRAPHS

The depositional histories of most of the samples in the thesis area are closely related. This makes the differentiation of individual environments of deposition from the bivariate plotting of grain size statistics very difficult, if not impossible. However, the plots presented in the Results section do serve to clarify extreme limits and most common values of these parameters. Improved results may have been obtained if samples had been sieved at 1/4 phi intervals, and if moment measures of parameters had been employed. However, moment measures would be an improvement over graphic statistics only if the 1st to the 99th percentiles could be accurately determined. (A time-consuming and difficult, if not impossible prospect for some of these samples.) It appears that the results of this exercise confirm what several authors have already determined, in that, unless extreme care is taken, grain size statistics are probably not sensitive enough to accurately distinguish between depositional environments. This is particularly true if the depositional environments are closely related, as in the case of surficial sediments in the Dunnville area. Grain size parameters often appear to be inherited from the characteristics of the immediate source, thus smearing any zones of distinct depositional environments on bivariate plots that other authors may have established. The sediment "sub-system" under investigation here (that is, the ancient Grand River/Lake Dunnville "sub-system") appears to be so small that sediment characteristics distinctive to each depositional environment (if they exist) did not have a chance to develop and come to equilibrium within the "active lifetime" of the sediments.

One realizes, after looking at many published bivariate graphs, that the boundaries established by the various authors may not be universally applicable to all sedimentary sub-systems. For

example, the locations of the boundary lines may "fluctuate", depending on the area investigated, and the relationship between units being compared. In areas where sedimentary deposits are closely related, it is probable that the grain size statistics of the different environments of deposition will tend to be similar. In fact, with a small area like the Dunnville delta/sand-silt apron/dune sub-system, it is extremely possible that samples of sediments from one environment may have "inherited" grain-size characteristics from their immediate source, and did not have a chance to come to equilibrium with the new environment, similar to the situation found by Friedman (1961, page 516). The possible "smearing" of the environmental boundaries makes the establishment of such boundaries on bivariate plots even more difficult. Also, for both Folk and Ward and moment statistics, not every bivariate graph produced will be able to show separation of environments. Depending on the characteristics of the sedimentary sub-system investigated, there may only be a select few bivariate plots that show arguable separation of environments.

Therefore, any limited geological "sub-system" or geographical area under study (ie. a thesis area) may have its own "signature" of grain size relationships, hence its own pattern(s) of plots.

The graphs presented in the Results section (Figures 31 to 36) illustrate the difficulty of attempting to distinguish depositional environments from bivariate plots of grain size parameters. Rarely is there seen an area of any graph that is the exclusive domain of any particular type of sample. The delta and stream terrace samples come the closest to establishing an "exclusive zone". As can be seen on the Mean vs. Skewness, Mean vs. Sorting and Mean vs. Kurtosis graphs (Figures 31, 34 and 36, respectively), these samples tend to plot toward the left edge of these graphs, by virtue of their generally coarser grain size.

The delta and stream terrace samples are not restricted to this area however, because on Figures 31, 34 and 36 they overlap areas where samples from all the other environments are common.

Inman (1949), Griffiths (1951), Inman and Chamberlain (1955), and others have shown that the best sorting values are attained by medium to fine sands, and that sorting becomes worse as the sediments get either finer or coarser (Folk and Ward, 1957). As there appears to be a general fining of grain-size from west to east in the thesis area (Figure 20), one might expect to see a corresponding worsening of sorting from west to east. This is only true in a very general way (Figure 21). It was then hypothesized that, once these two parameters (mean and sorting) were plotted against each other, a clear relationship could be depicted, resembling a linear diagonal pattern going from the northeast corner of the graph to the southwest corner.

When examining Figure 34 three very subtle trends can be distinguished, besides the central "core" of mixed samples. There appears to be a "tail" of dune samples coming from the central "core" and trending off to the northeast. A similar "tail" is seen for samples from the silt and sand apron unit (also referred to as the "silty/sand" unit) although at a different angle than the dune "tail". These two trends appear to be valid, although they have sparse data to enhance their appearance. Over 90% of all dune samples plotted on this graph occur within or very close to the central "core", and additional plotting of dune samples would only serve to further crowd the central core at the expense of possibly obtaining a few more data points in the dune sample "tail". The samples from the silty/sand unit appear to be evenly distributed throughout the central "core" and the tail they form. Further plotting of data points from this environment would likely enhance the "finer sediments = poorer sorting" pattern suggested here.

A third trend, that of the delta or stream terrace samples, appears to have an attitude at 90° from the dune and silty/sand ones. That is, it trends from the central "core" to a northwest

direction, instead of northeast. These data points are somewhat more dispersed in the area of the central "core" than the samples from other environments, and one gets the impression that the delta or stream terrace "tail" is shorter and stubbier (ie. less well defined) than that of either the dune "tail" or the silty/ sand unit "tail". Nevertheless, if one were to obtain more data points from the delta or stream terrace unit, the author is confident the trend suggested here would be significantly enhanced.

As stated earlier, about the only sediments falling into the "well-sorted" category would be the medium and fine sands, and all clays, silts and most gravels should be "poorly sorted" to "very poorly sorted". The frequent generalization that sorting increases with transport is, in many suites, simply due to the fact that the mean size of a sediment changes with transport, and the improvement in sorting is dependent only on the decreasing mean size, not the distance. As Inman (1949) suggested, once the sediment attains a minimum standard deviation (best sorting), if it continues to get finer, sorting will worsen with further transport (Folk and Ward, 1957). This seems to be the case when one observes Figure 34. The subtle trends on the graph appear to suggest the following hypothesis.

As the coarse sediments of the ancient Grand River approached Lake Dunnville, the coarsest particles (pebbles) along with some of the coarse sand, stopped being transported and came to rest in very poorly sorted terrace deposits. (The white triangles that plotted furthest away from the central "core" on Fig. 34.) In the relatively reduced-energy environment of the Dunnville delta, coarse sand with rare pebbles was deposited. (The white triangles that plotted in a dispersed pattern near the central "core".) The finer sand and silt tended to be swept further along the "system", to come to rest in the form of a thin apron at a more distal position from the main Dunnville delta. (These silt and sand samples plot as black triangles on Fig. 34)

The sediment of this system reached its optimum sorting value midway between losing most of its pebbles and being deposited as a silt and sand apron. This is the area of Figure 34 where the well-sorted end of the two trends (delta/stream terrace and the silty/sand unit) meet and overlap within the central "core". The fact that these two trends seem to "radiate" from the central "core" appears to support Inman's (1949) and Folk and Ward's (1957) suggestion of a "sorting path". In this case, a subtle "V" shape is obtained on the mean versus sorting graph. (See dashed line on Figure 34.)

The fact that the "tail" of dune sample data points trends to the northeast from the central "core" at a slightly different angle than the silty/sand unit samples suggests that dune samples are closely related to material from the silt and sand apron, but have, in addition, been subjected to a wind-derived sorting mechanism.

It is interesting to note that on Figure 34, the beach sand and till samples plot in two distinctly different areas of the graph, as opposed to the situation on most other graph Figures, where they seem to plot in fairly close proximity to each other.

On Figure 31, the samples labelled as being from an "unknown environment" and having a mean grain size finer than 5 phi include PD 192, PD 193, and PD 382. These are samples of sandy clay from the thesis area. Considering their surrounding stratigraphy, it is now known that these samples were deposited as lake-bottom sediments. It would be interesting to see if other samples from this depositional environment also plotted in this area of the graph. If they did, it would be a step toward establishing an environmental "field" on this graph. As it stands now, the establishment of a distinctive field on the basis of only a few samples is very ill advised.

Friedman (1961) concluded from his graphs that, for the most part, dune sands were positively skewed. (ie. They have an excess of finer material, or have had the coarse "tails" of their grain size distributions removed.) This also appears to be true for 70% of all the samples plotted on Figures 31, 32 and 33, notwithstanding Figure 39.

CORE PEEL PHOTOGRAPHY AND X-RADIOGRAPHY

Samples of core peels from the three main environments of deposition in the thesis area are included in Plates 5 to 11. Core peel imagery of delta (LC30, 31 and 32), dune (LC1, 3, 4, 25, and 26), and silty/sand apron (LC2, 13, and 24?) sediments are represented, as well as core peel imagery of lake bottom sediments (LC12 and 14). The core peel imagery provided an excellent way to observe and preserve the record of cored sediments, and is particularly useful in confirming laboratory observations of cores and core peels. They also made comparisons between individual cored intervals fairly convenient.

Photographs of cored dune sediments confirm distribution of fine/medium/coarse grained sand commonly seen in sand pit exposures. Core peel photographs were often the only way to observe sedimentary structures within the delta and/or silty sand apron deposits. This is because these units were either commonly water saturated, thus precluding the excavation of a pit for observation, or these units were too coarse grained to reveal much fine laminar detail in the field. In this latter regard, X-radiography of core peels proved to be very useful. See Plate 11 (LC31) for an excellent example. The detail provided by the imagery presented here would probably not have been visible by observing this deposit in the field.

Unfortunately, not all the X-radiographs are as useful as Plate 11A and B. All too often, the image on the X-radiograph appears as a mass of apparently random light and dark spots. This could have been avoided by X-raying the entire core before cutting. Alternatively, a more representative portion of the core could have been used, ie. using the half core available after cutting and subsampling, but before making the core peels. In this way, very faint structures that could have been present in the upper soil horizons may have been seen.

When making peels, the poor porosity and permeability of finer grained materials (silt and/or clay) prevented the white glue from penetrating the sediment very deeply, resulting in a peel consisting mostly of a hardened glue film with a minimum amount of sediment imbedded in it. The resulting portion of the X-radiograph appears as a dark area. A good example is the lower part of LC14, Plate 7B. The sub-horizontal white lines on the X-radiograph of this core peel are indicative of places where the massive clay of the core has dried and cracked while awaiting the peel process. These cracks then provide conduits for excess liquid glue at the time of making the peel. When the excess glue hardens, it forms a relatively thick lump which shows up on the X-radiographs as a white, sub-horizontal feature.

SITE SECTIONS

Six sample sites were selected as representative of the various facies of sandy Quaternary deposits in the Dunnville area. Site locations are shown on Figure 4, and interpreted facies relationships are illustrated on Figure 43. The sections, from west to east, are: the Dunnville Backyard Excavation; the Bird Road Excavation Site; the Horse Farm Section ; the Water Well Section; Cemetery Dune; and the Sod Farm Section. (Figures 44 to 49). The core examples used with the figures are the best available for that type of deposit, but may not portray all details displayed in the idealized section.

Dunnville Backyard Excavation (Figure 44):

This figure illustrates the type of sediment to be found in the local area around Dunnville, and is represented on Feenstra's (1974) map as part of a "stream terrace and deltaic sand" deposit (unit #9). The thin (1 metre) delta deposit, composed of coarse sand, lies directly on massive clay. The clay is interpreted to be a glaciolacustrine deposit of one of the glacial lakes from Lake Whittlesey to Lake Dunnville, and appears to underlie all the sandy deposits east of Dunnville.

The coarse sand unit at Dunnville is interpreted to represent a high-energy environment which would tend to discourage deposition of finer grained sediment. At some locations, the coarse sand contains some pebbles and/or mud balls. This may indicate a type of channel lag from a distributary channel of the delta, as the pebbles and mud balls are usually (though not always) found close to the base of the coarse sand unit.

Sedimentary structures could not be seen in this unit, but a slight fining upward trend is noted. The 45 to 60 centimetre thick deposit of fine sand on top of the coarse sand unit is

interpreted to represent a significant shallowing of Lake Dunnville, and partial exposure of the delta sediments to the air. No sedimentary structures were observed in this fine sand, so the environment of deposition is unknown. It is most likely that this material is an overbank-type deposit, formed when sediment was washed over the distributary channel banks of the delta.

Bird Road Excavation Site (Figure 45):

This section is interpreted to represent a delta deposit in a regime of medium to high energy processes. The location of this site is near the edge of Feenstra's (1974) "stream terrace and deltaic sand" unit.

The coarse to medium grained sand "package" just above the massive clay of the idealized section is very similar to the coarse sand deposit depicted in Figure 44, with the exception that this package is generally thinner, and parallel horizontal lamination can be seen. This appears to support the interpretation of a high-energy environment for this sand "package", similar to that of the deposit in Figure 44. However, the parallel lamination seems to indicate a somewhat more ordered deposition here.

The sudden change upward to a fine sand is representative of either: 1) a shallowing of water depth, and/or 2) a change in sediment supply, possibly the result of crevasse-splay or overbank processes. Both represent a drop from a high energy environment to a medium energy one.

The next sediment "package" seen here is composed of medium grained sand that has wavey cross-lamination. Such bedding may be representative of climbing ripples. This indicates a high sediment load in the depositional environment, which would not be unusual for a fluvial/deltaic system in a recently-deglaciated area such as this.

Horse Farm Section (Figure 46):

This section is believed to portray a facies of the distal portion of the Dunnville Delta, or the silty/sand unit on which the aeolian dunes are supposedly built. Feenstra (1981) states:

"Although most of the sand ridges on the delta plain are of eolian (sic) origin, there are some knolls of low relief (about one metre) which may have a different, perhaps subaqueous nearshore sand bar, origin. A section through one such knoll shows near-horizontally (sic) and contorted (slumping along the sides) stratified fine to very fine grained sand with minor medium sand, thinly intercalated".

Of the distal, eastern portion of the ancestral Grand River delta (the "Dunnville Delta", as it is referred to in this thesis), Feenstra states:

"The distal sequence consists here of about one metre of stratified, moderately well sorted, silty, fine to very fine grained sand...with some silt and little clay thinly intercalated. The sequence is current-stratified in its lower part. Individual sets of cross-strata indicate that the paleocurrent flow was consistently from westerly directions".

The author believes that the exposure at the Horse Farm Site (Figure 46) represents a section through both the "low knolls" and the "distal delta deposits" that Feenstra (1981) refers to. Exposures similar to the Horse Farm Section can be found at the "Yellow High" locations along Bird Road (Figure 4).

The idealized section on Figure 46 shows sediments with a great range of grain sizes resting on a base of massive clay, similar to the situation depicted on Figures 44 and 45. Directly above the massive clay is a package of alternating coarse and fine sand, having either parallel lamination, wavey bedding, or no bedding. Thin horizontal mud layers are included, but rare, in this package. Thus, this bottom half of the exposure appears to have been deposited under a variety of aquatic conditions, ie. irregular periods of cyclic current activity followed by quiescence.

Examples of deposits displaying this variety of grain size and

sedimentary structures are the delta-front facies of the Castlegate Sandstone (Van de Graff, 1972) or the distributary mouth bar deposits of a river-dominated delta, illustrated by Miall (1979). Miall's Figure 10 allows for several individual sequences of this type over an interval of approximately 100 metres, while Figure 46 (this work) is representative of part of a delta system that is probably orders of magnitude smaller, and appears to depict only one such cycle.

The upper half of the exposure at the Horse Farm Section consists of mostly clay or sandy clay deposits interspersed with dirty, fine to very fine sand beds of various thicknesses. This part of the section is interpreted to have been deposited in a very low-energy environment, possibly during long periods of standing water or ponding with little or no current activity, such as that of an interdistributary bay.

The very top of the idealized section on Figure 46 appears to consist of a relatively thin mantle of fine to very fine aeolian sand, similar to some of the material found at sites such as Cemetery Dune (Figure 48).

Individual beds in exposures like the Horse Farm Section may be fairly continuous and traceable <u>within the limits of the "knoll" itself</u>, but <u>cannot</u> be tied with beds in similar, distant exposures of other "knolls". This suggests the localized, almost random occurence of the different environments of deposition on the distributary plain of a delta in a very shallow lake. It is possible that parts of the delta were exposed to the air for varying lengths of time, resulting in small areas of crevasse-splay deposits, sheet sands and marsh deposits. A deposit similar to the levee-like deposits of the St. Clair River delta is envisaged (See following section on Depositional Environments and Sedimentology).

Water Well Section (Figure 47):

Located approximately 100 metres to the south of, and at the same topographic level as, the Horse Farm Section depicted in Figure 46, is the Water Well Section. The most striking feature of the Water Well Section is its fairly uniform texture of fine to medium sand, as compared to the wide variety of textures present at the Horse Farm Site. Also, approximately 20 metres away from the Water Well Section towards the Horse Farm Site, again at the same topographic level, a massive clay unit was found under a thin (20-30 centimetre) layer of fine sand. The surface of this massive clay unit appears to be a continuation of the one found at the base of the Horse Farm Section. The sudden lateral change from massive clay to fine sand at the Water Well Section suggests the presence of a channel-fill deposit. Exposures of this facies are rare in the thesis area, and the core example shown on Figure 47 is not representative. The interpretation of the sand in LC20 as a channel-fill deposit is questionable.

Having viewed the field maps of Feenstra and his assistants it is noted that discontinuous channels are interpreted to exist in the southeast corner of the silty/sand apron deposit. (These channels are not depicted on the published preliminary maps, of Feenstra, 1972 and 1974). This information, along with the suggestion of channel-fill deposits at the Water Well site, seems to indicate the possible presence of a network of preserved channels throughout the distal delta facies (silty/sand apron) of the thesis area. These channels are assumed to have been scoured into the glaciolacustrine massive clay unit at the time of active delta building, when the clay deposit had a high water content, theoretically making it softer and more susceptible to erosion.

Cemetery Dune (Figure 48):

The lower part of a dune exposure in the Dunnville area usually consists of a fine sand, very often with sub-horizontal or low angle bedding. Some graded beds can be seen, along with rare isolated examples of small scale cross-bedding, and layers of heavy mineral concentrations, particularly near the base of exposures. (Plate 19, A and B.) In exposures of dune material thicker than approximately 2 metres, the top of this fine sand sub-unit is usually an erosive contact with the coarser sub-unit above (Plate 18).

The upper sub-unit of a dune exposure thicker than 2 metres usually consists of fine and medium sand, with occasional coarse layers. This sand has high angle cross-bedding with certain grain sizes usually forming individual layers. Some graded bedding may be seen, as well as the occasional area of distorted bedding (Plate 2).

Feenstra (1972, 1974, 1981) makes no reference to the two sub-units of dune deposits in the Dunnville area. This leads to the question: "Which sub-unit is considered to be of aeolian origin, or are they both?" (See "Aeolian" section of "Depositional Environments and Sedimentology.") There was never really a question as to the presence of some type of aeolian deposit, because airphotos showed occasional well-shaped parabolic features. Field investigation confirmed the parabolic shape and slight elevation of these forms. Some topographically high spots in the thesis area also had relatively steep east faces, interpreted to be dune slipfaces. (See Figures 41 and 42.)

There were many subtle high spots in the map area that appeared to be less than 1 metre in height. Feenstra (1972, 1974) displays an abundance of parabolic features, but some of the low features had to be observed with an element of idealism to see them as being parabolic in shape.

Sod Farms Section (Figure 49):

Figure 49 depicts the type of deposit that can be expected at the extreme edges of the silty/sand unit. A typical exposure would have a base of massive clay, possibly laminated in the upper portion. This represents a glaciolacustrine deposit, probably of Lake Dunnville. The laminated clay then appears to coarsen upwards to interbedded clay and silt, with occasional layers of very fine sand. This indicates a transition from a glaciolacustrine evironment to an extreme distal delta setting. The sequence may be capped with a silty or clayey sand mantle, which is interpreted to be a portion of a low energy distal facies of the Dunnville delta, or possibly a veneer of very fine aeolian material.

The great abundance of mud, the thin horizontal to sub-horizontal laminations, and the lack of noticeable cross-bedding attest to the interpretation that this material was deposited in a low to very low energy environment.

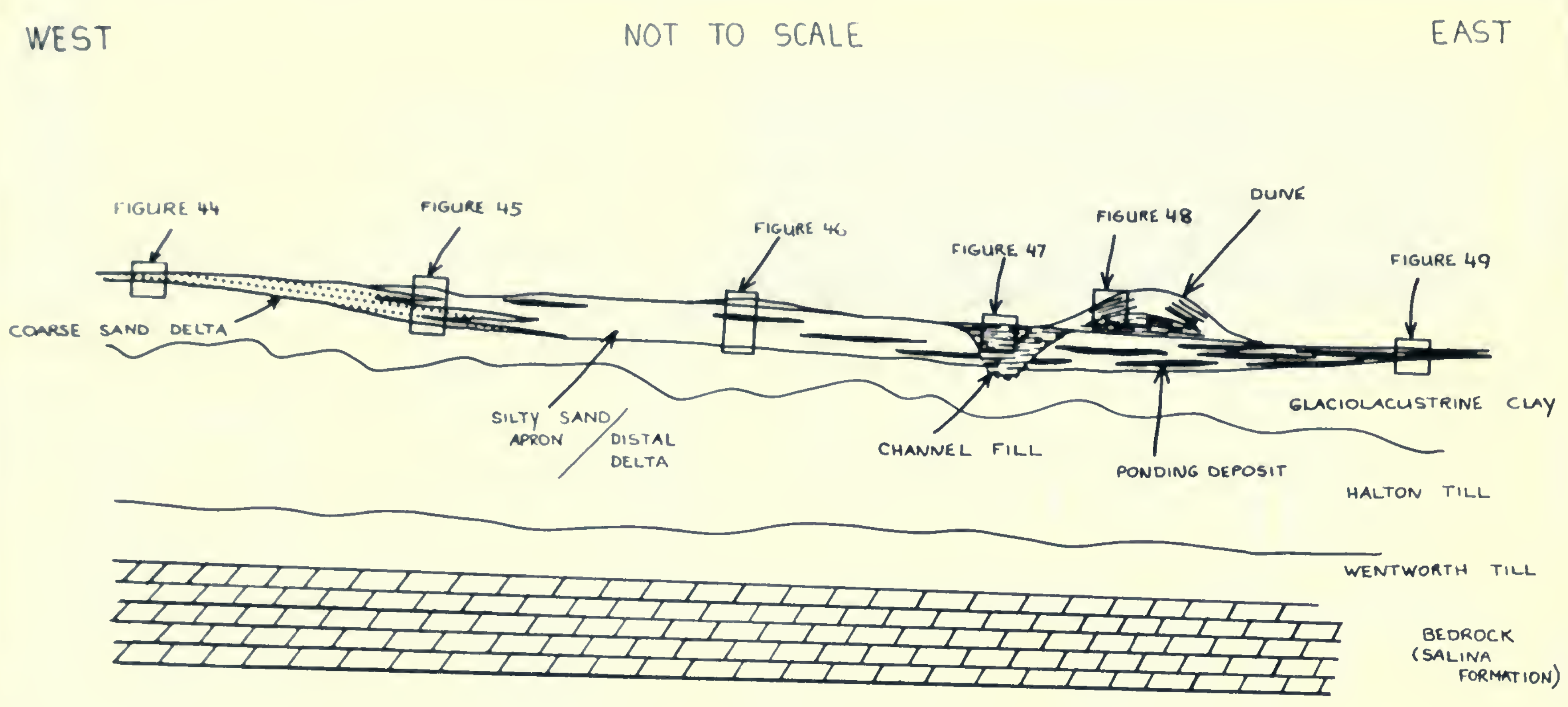


FIGURE 43
SCHEMATIC FACIES RELATIONSHIPS

DEPOSITIONAL ENVIRONMENTS AND SEDIMENTOLOGY

Deltaic

There is an immense volume of geological literature available dealing with deltaic sediments and environments. This literature is overwhelmingly concerned with marine-associated deposits. Fresh water lacustrine analogies are rare. The paper by Pezzeta (1973) on the St. Clair River delta (between Lake Huron and Lake Erie) affords an excellent opportunity for comparison of this active delta with the ancient Dunnville Delta system because they occur in similar physical settings, and certain aspects of their morphologies are much the same. Table 2 is a summary of similarities and differences between the two deltas. Field and laboratory observations suggest that the St. Clair River delta is a good model to use when attempting to conceive the nature of the Dunnville Delta during its active life.

Two of the most interesting deposits of the Dunnville Delta are illustrated on Figure 46: the Horse Farm Section, and Figure 47: the Water Well Section. If one accepts the interpretation of the sediments at the Water Well Section as being a channel fill deposit, then it is a small extrapolation of thought to conceive the sediments at the Horse Farm section to be a type of "levee deposit" along a distributary channel that has been incised into the pre-existing sediments. Channels and levees present on the St. Clair River delta plain were the models used for this interpretation of Dunnville Delta sediments. The "levees" appear to contain examples of both overbank deposits (sand) and possibly part of the sediments associated with interdistributary bays (clay and sandy clay).

Table 2: Comparison of the St. Clair and Dunnville Deltas

(Information in brackets was obtained from Pezzeta, 1973 (St. Clair delta); or Feenstra, 1981 and personal observations (Dunnville Delta system).)

Similarities: Mean grain size (St. Clair:3.35 Ø;Dunnville:3.0 Ø)
Fresh water environment
Mid-continental location
Same height above sea level (178 metres)
River discharges into a very shallow lake (6 to 7 metres deep)
Subdued relief in surrounding area

Similarities Envisaged by This Author:
Delta plain distributary system well developed
Incised distributary channels
Levees along distributary channels (?)
Presence of interdistributary bays

Differences: Delta front morphology
(St. Clair: steep; Dunnville: gentle)
Vegetation present during active life
(St. Clair: yes: Dunnville: no)
Associated aeolian deposits
(St. Clair: no; Dunnville: yes)
Length of active delta deposition
(St. Clair: 7500 years; Dunnville: much less than 900 years)

The "Differences" noted on Table 2 appear to be interrelated. The long life span of the St. Clair River delta (under relatively constant sediment load conditions), assisted in the formation of the steep delta front morphology. This is because sediment transported by the St. Clair River could only be carried a certain distance by any particular current strength before it was deposited. This limit, over the 7500 year life of the St. Clair River delta, would tend to form a sediment buildup having a particular "edge" (ie. the delta front edge). In contrast, the Dunnville Delta did not exist for a sufficient length of time to be able to form a steep delta front edge. All that was formed east of Dunnville was a very thin apron of fine sediments, particularly at the extreme eastern end.

The long active life of the St. Clair River delta also contributed to the opportunity for vegetation to establish itself on the exposed portions of this delta. With water covering the major portion of the St. Clair River delta, and vegetation covering any parts that were subaerially exposed, there was little opportunity for aeolian processes to affect the sediments. This is true even today. The exposure of the deltaic sediments at Dunnville, without the benefit of vegetative cover, lead to the aeolian erosion of these sediments and the subsequent deposition of this material as dunes.

Measurements extracted from water well records for the thesis area (Ontario Ministry of the Environment, 1978 and 1981) exhibit a rough measure of the thickness of surficial sand (deltaic and/or silty sand apron and/ or aeolian deposits). From 39 wells drilled in the area (from 1946 to 1975), the average thickness of sandy sediments that were encountered at ground level was 2.4 metres. This supports a general view of a thin deltaic "fan" being deposited over the bottom of Lake Dunnville. In addition to the 39 water wells noted above, there are five "anomalous" wells in the thesis area with surficial sandy deposits recorded as extending to 10, 17, 28, 29 and 30 metres depth.

It is postulated that the three thickest anomalous values are the result of driller error (recorded descriptions include: "sand plus clay", "topsoil plus clay" and "quicksand"). The two shallower anamolous values could conceivably be the result of drilling into one of the sand-filled distributary channels discussed above.

Aeolian:

As mentioned earlier, features less than 2 metres high in the thesis area seemed to be dominantly composed of the lower, fine grained dune sub-unit. Two interpretations are presented here for the origins of these low features. First, it is interpreted that the fine grained sub-unit was deposited soon after the draining of Lake Dunnville, as gently undulating "hummocks" over most of the thesis area. In this interpretation, the method of deposition was early stage aeolian transport of material from the recently exposed silty/sand apron. This material was then deposited as low dunes of varying morphologic maturity.

The second interpretation involves the deposition of these low features during the period when the distal part of the Dunnville Delta was being built up and/or dissected by distributary channels. The features would be deposited as bars on the delta plain, similar to those described by Galloway (1976) on the deltaic plain of the Copper River fan-delta, although the features described by Galloway are of a larger scale than those under discussion here.

The small-scale cross-bedding and heavy mineral layers seen in the lower unit on Plate 19 (A and B) would afford the impression that these sediments are water lain. Yet, these structures are not unknown in aeolian deposits. (P. David, Universite de Montreal, personal communication; Fryberger, et al, 1979). This makes it difficult to decide which interpretation of the origin of these low features is "correct". This problem is not uncommon when attempting to assign a process of deposition to a sand or sandstone unit. Some sandstone units in the western USA have been the subject of heated debate as to whether their mode of

Plate 18: Peel PD#5 (from Jenny Jump Pit)
Note erosive contact between lower, fine sub-unit and upper, coarse sub-unit; also note scattered root casts (white blebs).

A

B

PLATE 19: Jenny Jump Pit; Lower West Wall Detail.

A: Note heavy mineral concentrations in lower right corner.

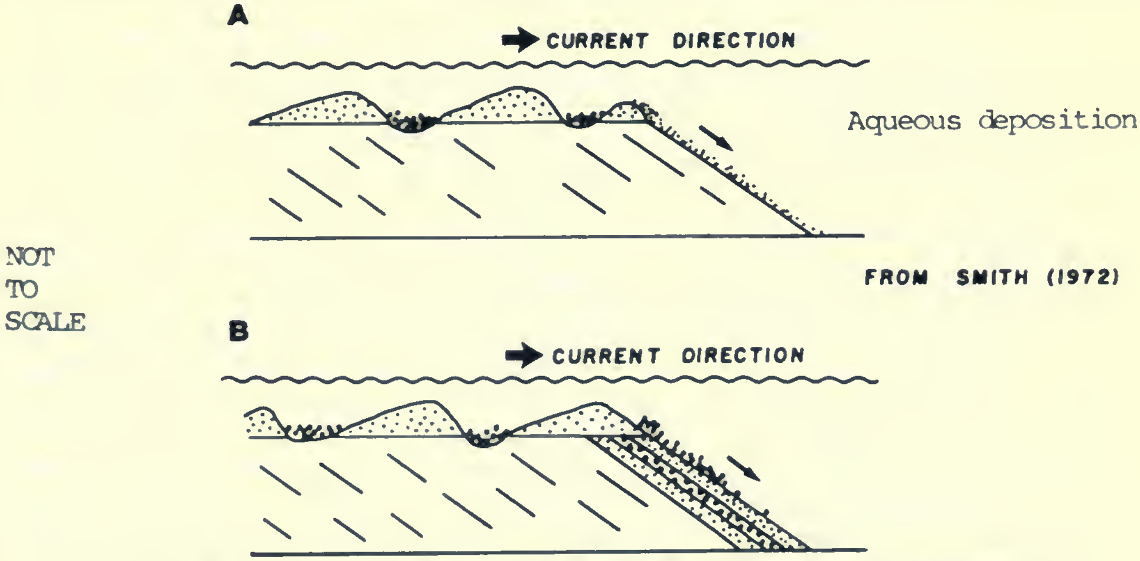
B: Close-up of lower left corner of A. Note isolated small scale cross-bedding. Length of small shovel handle is approximately 15 cm.

deposition was aeolian or shallow marine. Examples include the Navajo Sandstone (Walker, 1979), the Curtis Formation (Kocurek and Dott, 1981) and the Cedar Mesa Sandstone (Loope, 1984).

If one examines Plate 19A closely, particularly the area between the two shovels in the lower central part of the photograph, a light-coloured, roughly rectangular patch can be seen. It is postulated that this represents the cross-section of a small run-off channel. This structure is at the same level as the heavy mineral concentrations and the small scale cross-bedding seen in the same photograph. This appears to be evidence for suggesting that the lower, finer-grained sub-unit of the dunes was, at least occasionally, affected by water, and may in fact have been deposited mostly by water, not wind.

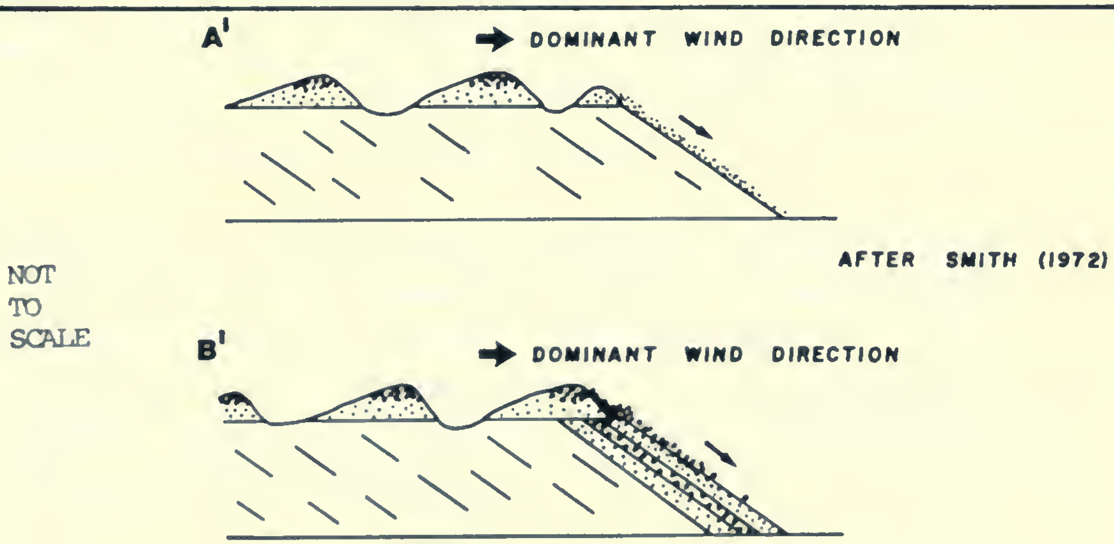
Regardless of the process of deposition, these low features seem to form the "core" of at least some of the larger, better developed dunes in the thesis area, including Hydro Hill and the Jenny Jump dune (parabolic); and Kentucky Hill and Cemetery Dune (longitudinal). All these dunes have an upper sub-unit of coarser sand, as described earlier. It is postulated that, during the aeolian action that deposited the upper, coarser sub-unit, many of the small, low amplitude features existed over the Dunnville delta plain, and some of them acted as "nucleii" for the growth of the larger aeolian features. The upper sub-unit is almost certainly of aeolian origin, although, as reported in the references cited above, it is not uncommon for sandstone units with "obvious" aeolian high angle cross-bedding to be reinterpreted as shallow aqueous deposits, then again reinterpreted as aeolian.

If the sedimentary structures of the upper sub-unit were formed subaqueously, it would be fairly easy to see how it could be interpreted that the lamina of alternating grain size could have been built up in the manner proposed by Smith (1972). In this process, subaqueous ripples with coarse grains segregated in their troughs act essentially as "conveyor belts" to transport sediment to the bar edge. Where avalanching is relatively continuous, coarse laminae originate when ripple troughs "dump" their sediment



A- Finer sediment composing the small scale asymmetrical bedform spills over the bar edge followed by:

B- Avalanching of coarse sediment previously segregated into leeside scour pocket. Thickness of laminae depends on length of foreset and size of surface bedforms.



Corresponding aeolian analogy.

Figure 50: Possible Origin of Coarse and Fine Foreset Laminae

on the slipface, and fine laminae form as ripple crests spill their sediment. (Kocurek and Dott, 1981) (Figure 50).

Kocurek and Dott (1981) are of the opinion that this same process is unlikely to operate on aeolian dunes because avalanching is rarely continuous, and the coarser grains segregated on wind ripple crests rarely constitute single grainflow laminae because of the smaller volume of material composing such a crest.

The author would tend to disagree with this opinion on the grounds that: 1) it is unknown why the criterion of continuous avalanching is necessary and 2) the volume of material necessary to produce beds of the thickness seen in Plate 2 could possibly be derived from storm actions, where high wind velocity would enable the transportation of larger amounts of mixed material (fine and coarse sand) than normal. Once this material was transported to the brink of a dune, sustained strong winds would favor keeping the smaller grained material in suspension, while dropping the coarser sand over the brink, thus forming more of a grainfall deposit than a grainflow one. The varying thicknesses of beds seen in Plate 2 also appears to support the non-constant (ie. storm-induced) deposition of some of the laminae. In this scenario, the laminae composed of finer material would probably be deposited during periods of calmer winds.

The occasional, relatively thick beds of coarse sand in the upper sub-unit may also be the result, in part, of a truncated ripple mechanism, such as that proposed by Steidtmann (1982). In his investigation of aeolian dune formation in a cold, moist climate, Steidtmann commonly found surficial ripples with truncated crests. His explanation is as follows:

"Apparently, sand is blown into ripple forms while dry and subsequently becomes moist during periods of precipitation and/or changes in groundwater level. Later exposure to drying conditions causes the crests to become remobilized before the remainder of the ripple form dries. Apparently this is caused by greater exposure of the crests to wind and sun. The result is that the crests are blown away while the troughs remain wet and intact." (Steidtmann, 1982)

As grains are commonly coarser on wind ripple tops than in adjacent swales (Spearing, 1971) it appears that there would be a short period of time (after the coarse material has dried and the remaining material is still damp and relatively immobile) when the particles available for transport would be dominantly coarse grained. During this time, the coarse particles would be carried over the brink of the dune and deposited as a relatively thick bed. The subsequent drying and transport of the remaining ripple material would tend to produce a graded bed on the slipface of the dune. (Plate 2; note thick, coarse grained layer in upper third of photo).

Steidtmann (1982) also describes other structures of sand dunes formed under cold, moist climate conditions. One should have these structures in mind while observing the dune deposits east of Dunnville, because a cold, moist climate was likely in existence in this area during the formation of the dunes. The proximity of the area to post-glacial lakes, the water-laid nature of closely associated deposits, and the presence of a glacial ice mass within approximately 300 km (inferred from Terasmae, et al 1972, Figures 2 and 3) would contribute to the assumption of a cold, moist climate. However, this is not to suggest that structures seen in the Dunnville dunes are exclusively the result of cold, moist climate conditions.

Figure 51 illustrates a situation apparently common among the larger dunes of the thesis area. Whereas the lower, fine grained sub-unit is not clearly seen as a "core" for this dune (Hydro Hill), a clear parabolic shape is evident, as is a relatively steep slipface and an upper "mixed" fine/medium/coarse grained sediment observed in pits and cores. The composition of LC24 is interesting in that a similar fine sand/dirty sand/ $\pm$ clay pattern was seen in the core from the base of the Jenny Jump dune (LC13) and the floor of Indian Dune (LC21). This suggests that the aeolian dunes were deposited directly on top of the distal delta sediments.

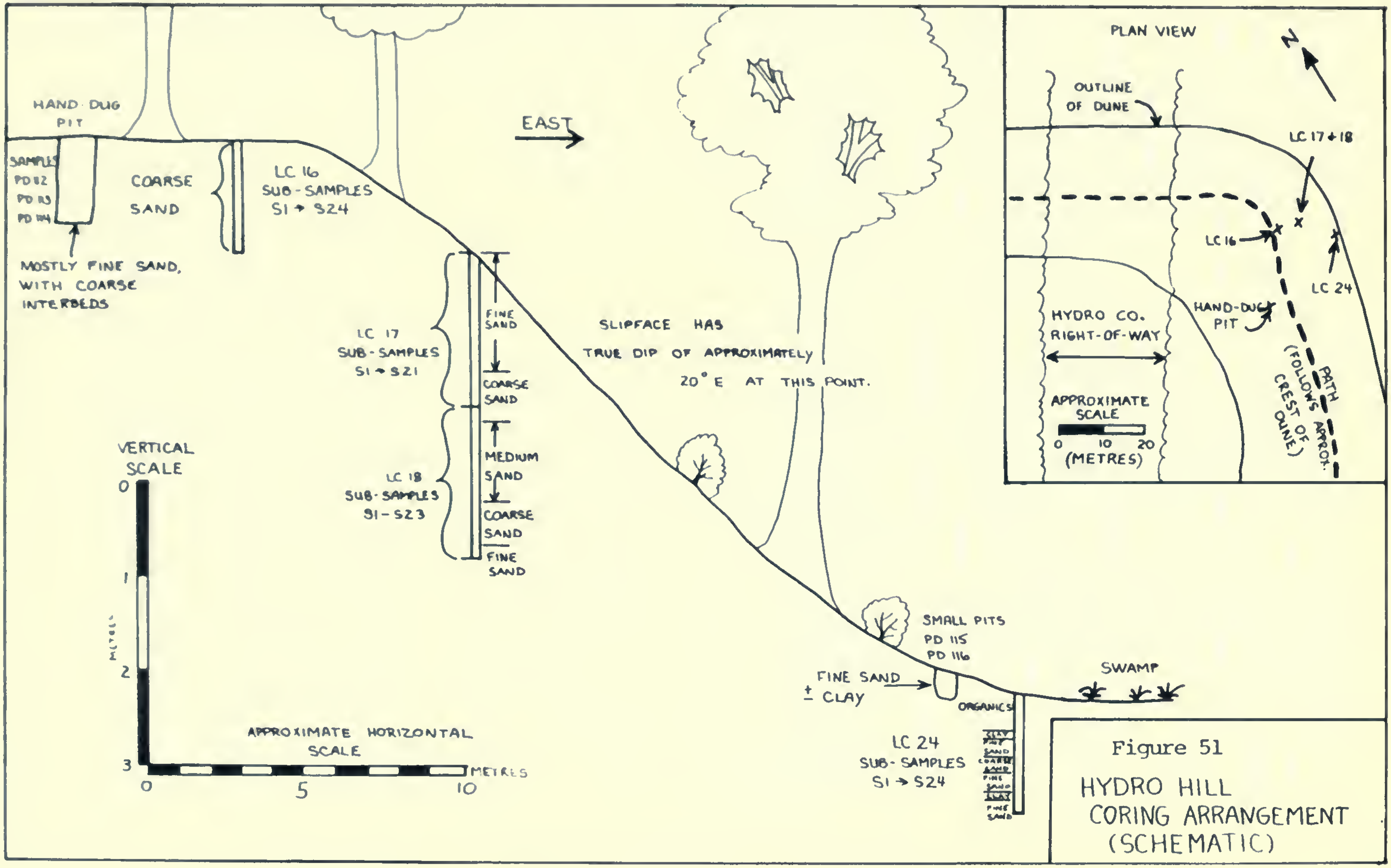


Figure 51
HYDRO HILL
CORING ARRANGEMENT
(SCHEMATIC)

Figure 56 (Appendix VI) is a plot of sample locations for the detailed sampling program at the Cemetery Dune Pit. It is also used as a reference figure for Figures 7 to 11. Note the opposing dips of bedding between the north and south "sections". This is to be expected in a longitudinal dune such as this one. As with most longitudinal dunes, the orientation of the long axis parallels the vector line of two converging wind directions. Sand is deposited on opposite sides of the dune ridge alternately by the two wind directions. The complex cross-bedding pattern expected near the crest of longitudinal dunes (illustrated by Bagnold (1941) and others), could not be seen in this dune, as massive slumping and vegetation obscured most of the central part of the pit wall, adjacent to the crest. Several hand-dug pits were excavated on the crest of this dune in an attempt to locate such cross-bedding. Overdeveloped soil horizons prevented the viewing of any such sedimentary structures.

ECONOMIC POTENTIAL

The high water table in the area can create problems for the extraction of any materials for commercial use. In addition, the small areal extent of the sand dune deposits as well as the fine to very fine grain size present, limits the economic usefulness of this material.

Despite these restrictions, the sand dunes provide the best potential for future economic development of non-bedrock aggregate resources in the thesis area. Residents in the area report that, in the past, sand has been extracted from small pits for construction aggregate (particularly road building) or land fill. The Aggregate Resources Inventory Paper of the Town of Dunnville (ARIP 67) (Ontario Geological Survey, 1984) states:

"The town has existing resources of sand capable of meeting some of the local demands for low specification construction products such as fill. The sand is generally unsuitable for high specification uses such as asphalt and concrete....The material extracted from the pits is generally suitable for granular borrow and acceptable to borderline for Granular Base Course C. The material may also be suitable for blending sand if the fines content is reduced."

Some dunes have been intensely exploited in the past. Butcher Dune and Bumble Bee Hill have been excavated nearly to grade. Local residents report that the Jenny Jump Hill and pit are presently only a fraction of their former size. Field observations confirm old, partially overgrown pit workings on the south side of Jenny Jump Road.

The owner of the Indian Dune property relates that material from that pit had been used by International Harvester for "foundry sand" or "core sand". This use appears to have been the only reported commercial utilization of the sand that does not involve bulk aggregate consumption. Other uses for the sand, such as the manufacturing of silicon carbide, silica brick, glass, sodium silicate, paint filler, etc. require a high-purity sand, usually significantly over 90% SiO_2, with as few impurities as possible. (Hewitt, 1963)

As can be seen from Appendix IX, the average SiO_2 content of samples analyzed by XRF is approximately 60%, with TFe_2O_3 assessment of between 1 and 2%. The second most common major oxide present in the sands is CaO, in the form of carbonate rock particles. Besides the L.O.I. value, the next most common weight percent value of the sands is Al_2O_3, either from the feldspar or the clay materials present.

The above listed impurities severely limit the commercial uses of sand from this area. An exception may be the use of the sand for "Sand-Lime Brick", which requires a minimum of 55% SiO_2. It should be noted, however, that the feldspar content of most of the sands available may prove to be a problem. (Hewitt, 1963)

Springer (1983) reports:

"...materials research from Europe (Fiori and Fabbi, 1983; Bansaghi and Szilagyi, 1983; Rak et al 1982; Fedelldshiev et al, 1979) suggests that quartz-feldspar mixtures of different origins may be used as ceramic feedstuffs, for stoneware, glazes, sanitary ware, and other ceramic bodies".

Raw materials described in the noted European references are much higher in feldspar content than the sediments studied in the thesis area. However, the presence of feldspar in sand from the thesis area should be noted if considering these sand deposits as raw materials for similar uses.

The natural clay content of some of the sand from the thesis area appears to be an advantage when considering the use of this material as foundry sand. An approximate range of clay content from 0 to 8% is available. The deeper deposits (the lower fine dune sub-unit and parts of the silty/sand apron) usually contain the higher percentages of clay. Hewitt (1963) states:

"For foundry sand, a highly refractory tough silica sand, having rounded grains with rough surfaces, is preferred. Depending on the size and type of casting, various size-grades of sand are used, graded according to the American Foundryman's Association specifications. The silica sands are bonded with clay, and rough grain surfaces improve the bonding power. Rounded grains are preferable to angular grains owing to the increase in permeability of the sand, which allows the escape of gases during casting. Both naturally bonded and artificially bonded sands are used."

The data from Appendix IX indicate that samples obtained from lower parts of exposures, as well as some of those taken from the coarse sand unit at Dunnville are the highest in SiO_2 content (ie. PD 82 and LC28 S9). Unfortunately, the lower parts of exposures are usually at, or near the water table of the area, making extraction difficult if not impossible. In addition, it seems that the coarse sand unit at Dunnville is too thin in most places to economically support its extraction.

It is suggested that, for purposes of construction aggregate and landfill, large dunes such as Hydro Hill, Cemetery Dune, Kentucky Hill and possibly the Mumby Road Dune (Plate 1B) may be successfully exploited. Much of Kentucky Hill has already been removed, but beyond the eastern boundary of the former pit operations, a sufficient volume of sand exists such that future extraction of this material may be profitable. The existance of permanent cultural features (buildings, cemeteries, etc.) and their associated setback requirements would severely restrict future development of some deposits.

ARIP 67 (Ontario Geological Survey, 1984) lists five sand pits licensed to extract material from the sand dune area. Ten unlicensed and/or abandoned pits are also listed. The only production figure available includes the production from both the five licensed sand pits as well as the one licensed bedrock quarry outside the thesis area, to the south of Dunnville itself. The average annual production from all pits and the quarry in the seven-year period between 1974 and 1980 has been approximately 263,000 tons (239,000 tonnes) (Ontario Geological Survey, 1984)

It should be noted that the area of the Dunnville deltaic/aeolian sediments has no potential for bedrock resources, as the entire area is underlain by Salina Formation at a depth of between 25 to 40 metres (Ontario Geological Survey, 1984) varying potential for bedrock resources (poor to good) exists to the south, between the Onondaga Escarpment and Lake Erie.

In the thesis area proper:

"Several sand deposits have been selected"...(by the Ontario Geological Survey)... "for possible resource protection at the secondary level of significance. Since the sand and gravel deposits in the town are capable of supplying aggregate suitable for only a restricted range of low-specification products, and are generally of limited areal extent, no deposits have been selected at the primary level of significance". (Ontario Geological Survey, 1984)

The sand deposits mentioned in the above quote include most of the larger sand dunes to the east of Dunnville.

FURTHER STUDY:

As with most investigations, this study precipitated several questions, some of which may be answered with further research.

A coring program consisting of continuous boreholes from surface to massive clay (glaciolacustrine deposits) should be performed in a straight line over the crest, and on either side of a large dune, perhaps Hydro Hill. These boreholes would most likely be at least 6 metres deep. Vibracoring equipment is suggested for obtaining these cores. This program would help to clarify the hypothesis that the aeolian dunes were deposited directly on top of the distal delta sediments. Alternatively, a fresh exposure completely through a dune would provide even more information. Problems with obtaining such an immense cross-section include locating an appropriate site, obtaining the owner's cooperation, hiring a front-end loader for the excavating, and removing trees and their roots along the cross-section line. Even if all these stipulations can be met, the high water table in the area would likely prohibit an unflooded exposure of sediments below regional grade.

The proposed interpretation of the presence of infilled distributary channels and associated levees could be investigated by a concentrated coring program over an area where they are believed to exist. Alternatively, a very shallow seismic program could be employed to determine if infilled channels can be located and traced by this method. This information will be potentially useful in the study of groundwater flow patterns in the area. Large infilled channels may also be a potential source of fine-grained aggregate, if the size of the deposit warrants the expense of dewatering and/or wet extraction of the material.

In terms of the mapping of grain size parameters over the area, it might be worthwhile to employ moment statistics rather than Folk and Ward (graphic) statistics in order to try and establish sedimentation patterns. In this way, it would be simpler

to compare results obtained with published material. The detailed analysis of heavy and light minerals could provide some information on regional dispersal patterns as well as localized sources of dune material. An examination of sand grain surface textures, as well as a survey of dune sizes over the thesis area, could supply similar data.

A more intense search for materials dateable by radiocarbon methods could be conducted. This material may also supply samples suitable for palynological examination. It has been suggested (J. Flint, 1982 personal communication) that material from the Wainfleet Bog be examined for evidence of aeolian sand "stringers" that could be affiliated with sediments east of Dunnville. Dating the peat associated with such "stringers" may enable a minimum age to be assigned to the existence of the sediments.

A critical examination of sample grain size distribution could be done with the aim of determining the relative importance of traction, saltation and suspension populations. This could be related to the strength of the depositing wind.

Further study may also reveal the reasons for the existence of a major dune (Kentucky Hill) and what appears to be an extension of the silty/sand apron (Feenstra, 1974, unit #8) to the north of Dunnville. The interpretation of shallow water deltaic deposition coupled with the paleowind direction from the west makes little allowance for such sediments being deposited at that particular location.

SUMMARY AND CONCLUSIONS

The surficial deltaic and aeolian sediments east of Dunnville, Ontario have been examined in detail. The following conclusions have been established and/or clarified:

Sedimentary environments of various deposits in the thesis area have been reconstructed in more detail than has previously been attempted. It is concluded that the sediments of the coarse sand delta, silty/sand apron and inland aeolian dunes are intimately related in terms of source and facies relationships. The existence of delta plain distributary channels and associated levees has been suggested. The discovery of distinct upper and lower sub-units within some aeolian dunes has been documented. The lower, fine grained sub-unit is interpreted to be an immature aeolian deposit, or water-laid bars on the Dunnville Delta plain. The upper, coarser grained sub-unit is interpreted to have been formed by small-scale avalanching of aeolian material. The distinct beds of diverse grain size may have been deposited during times of varying moisture conditions.

The methodology of field and laboratory examination of unconsolidated sediments has been presented and documented in detail, including the development of a Grain Size Analysis Manual Worksheet.

By inference with previous work, it is concluded that the aeolian dunes were formed under cold, moist conditions between 12,300 to 12,100 years BP. Peat, similar to that found by earlier workers in the Dunnville area, has provided an age of 225$\pm$ 100 years (BGS 795). The morphology and mineralogy of some of the dunes indicate that they are composed of sediments that were not active long enough to become reworked into mature landforms, and that the source for the dune sands themselves was probably local. (See next page)

Core peel photographs, X-radiographs, core descriptions and site sections presented in this thesis document different sediment and soil types and conditions present at selected locations throughout the thesis area. As well as providing a permanent record of general sediment characteristics, these photos and diagrams, particularly the site sections (Figures 44 to 49) document development of the author's proposed schematic facies relationships (Figure 43).

Mapping of grain size statistics (as well as calculating "best fit" lines and correlation coefficients of data over the thesis area) resulted in the documentation of a general fining of mean grain size to the east. When sorting values were mapped, no clear trends were determined, except for the point that large dunes generally seemed to have better sorting. A skewness value map shows no pattern over the thesis area. Most samples analyzed have a nearly symmetrical distribution or were slightly positively skewed. Similarily, when kurtosis values were mapped, no coordinated arrangement could be seen. Most samples were leptokurtic to some degree, showing a strong central peak. The detailed examination of maps of % Sand, % Silt, % Clay and Mean Ø values also supports the hypothesis that the source for the dune sands themselves was <u>immediately</u> local (ie. material for dune construction probably came from an area of the silty/sand apron immediately upwind of each dune).

Detailed sampling of a single exposure by various methods reveals that the numerical values of statistical parameters can vary according to the type of sampling method used, and that caution should be exercised when interpreting such values, and extrapolating such data to the rest of the deposit.

It was confirmed that Folk and Ward graphic statistics are not directly compatible with calculations of moment parameters. When grain size statistics were plotted on bivariate graphs, no distinct separation of samples according to environment of deposition was seen, although these graphs are not without their uses. For example, the mean versus sorting graph appeared to be useful in directing attention to a regional sorting trend.

The bivariate graphing exercise supports the findings of other authors in that, unless extreme care is taken, grain size statistics are probably not sensitive enough to accurately distinguish between depositional environments. This is especially true if the sediments are closely related and within a small sub-system where they were not transported for a long enough period of time to come to equilibrium with their environment of deposition, before being preserved. In this regard, it is concluded that each geologically and geographically distinct area or "sub-system" <u>may</u> have its own "signature" of grain size relationships, hence its own pattern of bivariate plots. This would then require interpretation of patterns unique to each individual "sub-system" in order to investigate interrelationships between samples and environments within that "sub-system", rather than using bivariate plots of grain size parameters to attempt to differentiate between various environments.

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APPENDICES

I. Sample Descriptions and Grain Size Parameters

II. Freeze-drying comparison

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APPENDIX I: Sample Descriptions and Grain Size Parameters

Key to short forms used in Appendix I (A and B):

Calc.	=	calculation
Ex.	=	excavation
Flr.	=	Floor
H.M.	=	heavy mineral
Horiz.	=	horizontal
Indust. Pk.	=	Industrial Park
J.J. Pit	=	Jenny Jump Pit
J.J. Rd.	=	Jenny Jump Road
Junct.	=	Junction
Mott.	=	Mottled or Mottling
Pt. Mait.	=	Port Maitland
Sep.	=	Separation
Sd.	=	Sand
U. and L.	=	Upper and Lower
x-bedding	=	Cross-bedding
Y. High	=	Yellow High

APPENDIX IA: Sample Descriptions

SAMPLE	LOCATION	DESCRIPTION	NOTES	SAMPLE COLLECTION METHOD	ENVIRONMENT	H.M. SEP.	XRF
PD Series							
7A	J.J. Pit	Sand	Above red layer	Spot	Dune	No	Yes
7B	J.J. Pit	Sand-red layer	Red layer	Spot	Dune	No	Yes
7C	J.J. Pit	Sand	Below red layer	Spot	Dune	No	Yes
10A	J.J. Pit	Sand	Bulk sample	Bulk	Dune	Yes	No
16	J.J. Pit	Tan Sand	Unweathered sand	Spot	Dune	No	Yes
17	J.J. Pit	Sand	Transition material	Spot	Dune	No	Yes
18	J.J. Pit	Red sand	Red, weathered material	Spot	Dune	No	Yes
22	S. Side of Grand River	Coarse Sand	WNW of Dunnville	Spot	Terrace	Yes	No
23	W. of Byng	Till	Wentworth Drumlin	Spot	Glacial till	Yes	No
26	Byng Gravel Pit	Sand & Gravel	Glaciofluvial?	Lamination	Terrace ?	Yes	No
28	Byng Gravel Pit	Gravel	Glaciofluvial?	Lamination	Terrace ?	No	Yes
31	Grand R. Terrace	Gravel & Sand		Spot	Terrace ?	Yes	No
82	Gerry's Dune	Sand	Trench Sample	Spot	Dune-Lower?	No	Yes
129	Cemetery Dune	Fine Sand	South Section-Upper	Lamination	Dune-Upper	No	No
130	Cemetery Dune	Coarse Sand	South Section-Upper	Lamination	Dune-Upper	No	No
131	Cemetery Dune	Medium Sand	South Section-Upper	Lamination	Dune-Upper	Yes	No
132	Cemetery Dune	Sand	South Section-Upper	Lamination	Dune-Upper	Yes	No
133	Cemetery Dune	Coarse Sand	South Section-Upper	Lamination	Dune-Upper	Yes	No
134	Cemetery Dune	Fine Sand	South Section-Upper	Lamination	Dune-Upper	No	No
135	Cemetery Dune	Coarse Sand	South Section-Upper	Lamination	Dune-Upper	No	No
136	Cemetery Dune	Fine Sand	South Section-Upper	Lamination	Dune-Upper	No	No
137	Cemetery Dune	Coarse Sand	South Section-Upper	Lamination	Dune-Upper	No	No
138	Cemetery Dune	Fine Sand	South Section-Upper	Lamination	Dune-Upper	No	No
144	Cemetery Dune	Fine Sand	South Section-Upper	Lamination	Dune-Upper	No	No
145	Cemetery Dune	Coarse Sand	South Section-Upper	Lamination	Dune-Upper	No	No
146	Cemetery Dune	Sand	South Section-Upper	Spot	Dune-Upper	No	No
147	Cemetery Dune	Sand	South Section-Upper	Spot	Dune-Upper	No	No
148	Cemetery Dune	Sand	South Section-Upper	Spot	Dune-Upper	No	No
151	Cemetery Dune	Sand	South Section-Upper	Spot	Dune-Upper	No	No
152	Cemetery Dune	Sand	South Section-Upper	Spot	Dune-Upper	No	No
153	Cemetery Dune	Sand	South Section-Upper	Spot	Dune-Upper	No	No
155	Cemetery Dune	Fine Sand	South Section-Lower	Spot	Dune-Lower	No	No
158	Port Maitland	Gravel/Sand	Beach Sand	Channel	Beach	No	Yes
160	Grand R. Bank at Pt. Mait.	Sand	Terrace/Beach/Delta?	Channel	Unknown	Yes	No
162	Bird Rd. Ex.	Grey Sand	Parallel Laminated	Spot	Delta	Yes	No
166	Bird Rd. Ex.	Sand	Parallel Laminated	Spot	Delta	No	No
175	Hwy. 3 & Crown Rd.	Red Sand	Pebbles and clay balls present	Channel	Delta?	Yes	No

SAMPLE	LOCATION	DESCRIPTION	NOTES	SAMPLE COLLECTION METHOD	ENVIRONMENT	H.M. SEP.	XRF
PD Series cont'd...							
182	Horse Farm	Fine sand	Lower Third	Channel	Delta?	No	No
183	Horse Farm	Coarse sand	Lower Third	Lamination	Delta?	No	No
184	Horse Farm	Fine sand	Lower Third	Lamination	Delta?	Yes	No
185	Horse Farm	Coarse sand	Lower Third	Lamination	Delta?	Yes	No
186	Horse Farm	Fine sand	Lower Third	Lamination	Delta?	No	No
187	Horse Farm	Coarse Sand	Lower Third	Channel	Delta?	No	No
188	Horse Farm	Fine sand	Lower Third	Lamination	Delta?	No	No
189	Horse Farm	Medium sand	Middle Third Wavey bedding	Lamination	Unknown	Yes	No
190	Horse Farm	Fine sand	Middle Third Horizontal bedding	Channel	Unknown	No	No
191	Horse Farm	Coarse/Fine Sand	Middle Third Wavey bedding	Channel	Unknown	Yes	No
192	Horse Farm	Grey Clay	Middle Third(Freeze-dried)	Channel	Unknown	No	No
193	Horse Farm	Sandy Grey Clay	Middle Third(Freeze-dried)	Channel	Unknown	No	No
194	Horse Farm	Orange/Grey Sand	Upper Third Horizontal Mottling	Channel	Dune?	No	No
195	Horse Farm	Orange/Grey Sand	Upper Third Horizontal Mottling	Channel	Dune?	Yes	No
196	Horse Farm	Orange/Grey Sand	U. Third Horiz. Mott.-freeze-dried	Channel	Dune?	No	No
197	Horse Farm	Black Organic Sand	Upper Third(Soil)(Freeze-dried)	Channel	Dune?	No	No
198	Horse Farm	Brown Sand	Upper Third(Soil)(Freeze-dried)	Spot	Dune?	No	No
199	Horse Farm	Orange Sand	Upper Third(Soil)(Freeze-dried)	Spot	Dune?	No	No
202	Well Ex.	Medium/Fine Sand	Approx. Horiz. bed., H.M. Conc.	Spot	Delta?	Yes	No
218	Crown Rd. Ditch Junct.	Sand	Wavey bedding, H.M. Conc.	Spot	Delta?	Yes	No
229	Ditch W. of	Coarse Sand	Water saturated when collected	Spot	Unknown	No	No
	Crown Rd.			Spot			
251	Farr Pit	Fine/Medium Sand		Spot	Dune	Yes	No
255	Farr Pit	Fine Sand		Spot	Dune	No	No
263	Booker Rd.	Sand	Dune not on Feenstra's Map	Spot	Dune	Yes	No
281	Mrs. B's Farm	Coarse Sand	Mottled Orange	Spot	Dune?	Yes	No
282	Mrs. B's Farm	Sand	Mottled Orange	Spot	Dune?	No	No
287	Cemetery Dune	Mixed Sand	U. and L. Sub-units-S. Section	Channel	Dune	No	Yes
288	Cemetery Dune	Mixed Sand	U. and L. Sub-units-N. Section	Channel	Dune	No	Yes
289	Cemetery Dune	Fine Sand	Lower Unit only-South Section	Channel	Dune	No	No
291	Cemetery Dune	Fine Sand	Lower Unit + Pit Sand-S. Section	Channel	Dune	Yes	No
292	Indian Dune	Fine + Coarse Sand	Upper Coarse Sub-unit	Channel	Dune	Yes	Yes
293	Indian Dune	Fine Sand	Lower Fine Sub-unit	Channel	Dune	Yes	Yes
294	J.J. Pit	Coarse + Fine Sand	West Face-Upper Sub-unit	Channel	Dune	Yes	Yes
295	J.J. Pit	Fine Sand	West Face-Lower Sub-unit	Channel	Dune	No	Yes
296	J.J. Pit	Fine Sand	West Face-Lower Sub-unit	Channel	Dune	Yes	No
297	J.J. Pit	Coarse/Fine Sand	West Face-Upper Sub-unit	Channel	Dune	No	No
303	S. Side J.J. Rd.	Sand		Channel	Dune?	No	No
307	Hydro Hill Pit	Sand		Channel	Dune	Yes	No

SAMPLE	LOCATION	DESCRIPTION	NOTES	SAMPLE COLLECTION METHOD	ENVIRONMENT	H.M. SEP.	XRF
PD Series cont'd...							
308	Hydro Hill Pit	Sand		Channel	Dune	Yes	Yes
309	Mrs. B's Farm	Sand	Orange + Tan Sand	Channel	Unknown	No	No
311	Bumble Bee Hill	Sd w/coarse lens	Upper and Lower Sub-units	Channel	Dune	No	No
313	Bumble Bee Hill	Fine Sand	Lower Fine Sub-unit	Channel	Dune	Yes	Yes
314	Bumble Bee Hill	Sd w/coarse lens	Upper Sub-unit	Channel	Dune	Yes	Yes
315	Bumble Bee Hill	Fine Sand	Upper Fine Sub-unit (no coarse)	Channel	Dune	Yes	No
317	Bumble Bee Hill	Sand	Floor of Pit Horiz. layered	Channel	Unknown	Yes	No
318	Bird Rd. Y. High	Sand	Sample from below clay	Channel	Unknown	No	No
320	Bird Rd. Y. High	Sand + Clay		Channel	Unknown	No	No
324	Bird Rd. Y. High	Sand	Horizontal bedding	Channel	Unknown	No	No
325	Bird Rd. Y. High	Coarse/Med. Sand	Sample over clay	Channel	Unknown	Yes	No
333	Dunnville	Coarse Sand	Indust. Pk. Ditch (+pebbles)	Channel	Delta	Yes	No
337	Dunnville	Grey Sand	Backyard Ex. (above clay)	Channel	Delta	Yes	No
338	PD Dune	Sand		Channel	Dune	Yes	No
339	PD Dune	Sand		Channel	Dune	No	No
340	PD Dune	Sand		Channel	Dune	No	No
341	No Rd. Y. High	Sand	Above clay wispy X-bedding	Channel	Unknown	Yes	No
342	No Rd. Y. High	Mottled Sand	Orange and grey	Channel	Unknown	No	No
350	Townline Rd.	Mottled Sand	Orange and grey, trace bedding	Channel	Dune?	No	No
352	Jim's Y. High	Sand	Below B Horizon	Channel	Dune?	Yes	No
357	Jim's Y. High SE	Pink Sand	Just above clay	Channel	Unknown	No	No
360	Kentucky Hill	Fine/Coarse Sd.	Upper Sub-unit	Channel	Dune	Yes	No
361	Kentucky H. Pond	Sand		Channel	Dune?	Yes	No
364	Plattby Pit	Sand		Channel	Dune	Yes	No
367	Plattby Property	Fine Sand		Channel	Dune	No	No
369	Cemetery Dune	Sand	Trace bedding	Channel	Dune	Yes	No
372	Cornfield N. of R.R. Tracks	Clay + Sand	Freeze-dried	Channel	Unknown	No	No
375	Pepper Dune	Sand	Cider Rd.	Channel	Dune	Yes	No
376	N. of Winger	Sand	Parallel bedded	Channel	Unknown	Yes	No
377	Winger Rd. North	Grey sand	Massive	Channel	Silty/Sand Unit	Yes	No
379	Winger Rd. North	Sand		Channel	Silty/Sand Unit	No	No
382	Bell/Pettit Rds.	Clay + Sand	Freeze-dried	Channel	Unknown	No	No
386	Hwy. 3	Sand	Dune not on Feenstra's map	Channel	Dune?	Yes	No
387	Burned-out Farm Hwy. 3	Sand	White/orange	Channel	Dune?	Yes	No
388	Old Orchard Hwy. 3 (Farr's)	Fine Sand		Channel	Dune	Yes	No
390	Crown Rd. North	Grey sand	North of Hwy. 3	Channel	Dune	Yes	No
395	Hutchinson Rd.	Fine Dirty Sand	Grey and Pink finely bedded	Channel	Unknown	Yes	No

SAMPLE	LOCATION	DESCRIPTION	NOTES	SAMPLE COLLECTION METHOD	ENVIRONMENT	H.M. SEP.	XRF
PD Series cont'd...							
397	N. Hines	Fine Sand		Spot	Unknown	Yes	No
403	Murby Rd.	Dry Sand	Dune crest S. of R.R. Tracks	Channel	Dune	Yes	No
408	Crown Rd.	Tan Sand	East of Aiken Rd.	Channel	Dune	Yes	No
410	Rooker Rd.	Medium Sand	North of Rattlesnake Rd.	Channel	Dune	Yes	No
413	Poth Rd.	Sand/Clay	Near North Sod Farms	Spot	Silty/Sand Unit	Yes	No
414	Hutchinson Rd.	White/Orange Sand	1 km South of Hwy. 3	Channel	Dune	Yes	No
N Series							
02	J.J. + Crown Rds.	Grey Sand	Very wet when collected	Channel	Unknown	No	No
07	Dunnville	Coarse Sand	Aggregate supply yard	Grab	Unknown	No	No
08	W. of Dunnville	Coarse Sand	Grey + Orange	Spot	Delta?	Yes	No
09	Kentucky Hill	Mixed Sand	Upper Sub-unit	Channel	Dune	Yes	Yes
11	Byng County	Till	Halton Till (Freeze-dried)	Spot	Glacial Till	Yes	No
12	L. Erie Dunes	Sand	Modern Beach Dunes	Spot	Dune	Yes	No
13	Port Maitland	Clean Sand		Channel	Dune?	Yes	Yes
16	Double Horseshoe	Layered Sand		Channel	Dune	Yes	No
18	West Poth Rd.	Mixed Sand	Orange + White	Channel	Silty/Sand Unit	No	No
19	West Poth Rd.	White Sand		Channel	Silty/Sand Unit	Yes	No
22	Hutchinson Rd.	Grey Sand	Layered	Channel	Dune	Yes	No
23	Aiken Rd.	Grey Sand	Layered	Channel	Silty/Sand Unit?	Yes	No
24	S. Bird Rd.	V. Fine Sand	Below spring line (pebbles)	Spot	Unknown	Yes	No
25	S. Bird Rd.	Coarse Sand	Above spring line (layered)	Spot	Dune?	Yes	No
29	Sand Farmers Pit	Coarse/Fine Sd.	Upper unit	Channel	Dune	Yes	Yes

SAMPLE	LOCATION	DESCRIPTION	NOTES	SAMPLE COLLECTION METHOD	ENVIRONMENT	H.M. SEP.	XRF
Core Sample Series							
LC1 S12	J.J. Pit Flr.	Layered Sand		Core	Dune	Yes	No
LC2 S22	Gerry's Dune	Layered Sand	Core taken in swamp	Core	Unknown	Yes	No
LC3 S7	Gerry's Dune	Sand	Corner of Trench	Core	Dune	Yes	No
LC4 S14	Gerry's Dune	Sand		Core	Dune	No	No
LC5 S9	Gerry's Dune	Red Sand		Core	Dune	No	No
LC6 S7	Gerry's Dune	Sand		Core	Dune	No	No
LC7 S17	Gerry's Dune	Bedded Sand	Core taken in swamp	Core	Unknown	No	No
LC8 S13	Gerry's Dune	Sand		Core	Dune	No	No
LC9 S8	Gerry's Dune	Orange Sand		Core	Dune	No	No
LC9 S20	Gerry's Dune	Yellow Sand		Core	Dune	Yes	No
LC10 S15	Gerry's Dune	Grey/Yellow Sd.		Core	Dune	Yes	No
LC11 S19	Sod Farms	Medium Grey Sd.		Core	Silty/Sand Unit	Yes	No
LC12 S19	Townline & Bell Roads	Fine/Medium Sd.	Freeze-dried	Core	Unknown	Yes	No
LC13 S9	J.J. Dune Base of Slipface	Medium Grey Sd.		Core	Unknown	Yes	No
LC13 S20	J.J. Dune Base of Slipface	Med./Coarse Sd.	Wavey bedding(freeze-dried)	Core	Unknown	Yes	No
LC14 S6	Ex-Cedar Swamp	Dirty Grey Sd.		Core	Silty/Sand Unit	Yes	No
LC15 S9	Ex-Cedar Swamp	Dirty Sand	Orange and Grey(freeze-dried)	Core	Silty/Sand Unit	No	No
LC16 S23	Hydro Hill-Crest	Coarse/Yellow Sd.		Core	Dune	Yes	No
LC17 S13	Hydro Hill-Slope	Tan/Yellow Sd.		Core	Dune	Yes	No
LC18 S24	Hydro Hill-Slope	Coarse Sand	Bedded Sand	Core	Dune	Yes	No
LC18 S33	Hydro Hill-Slope	V. Fine Sand	Freeze-dried	Core	Dune	Yes	No
LC19 S8	Cemetery Dune	Sand	Pit Floor	Core	Dune	No	No
LC20 S20	Cemetery Dune	Sand	Pit Floor	Core	Dune	Yes	No
LC21 S11	Indian Dune Pit	Tan Sand	Water escape Structures	Core	Dune?	Yes	No
LC21 S15	Indian Dune Pit	Silty Sand		Core	Unknown	No	No
LC22 S13	Hammer Hill	Tan/Yellow Sd.	No bedding seen	Core	Dune	No	No
LC22 S24	Hammer Hill	Sand	Good bedding	Core	Dune	No	No
LC23 S17	Hammer Hill	Orange/Grey Sd.	Well-defined structures	Core	Dune	No	No
LC23 S22	Hammer Hill	Fine Sand	Fine Laminae	Core	Dune	Yes	No
LC23 S29	Hammer Hill	Coarse Grey Sd.		Core	Dune	Yes	No
LC24 S10	Hydro Hill-Base	Dirty Sand	Base of Slipface	Core	Unknown	No	No
LC24 S13	Hydro Hill-Base	V. Coarse Sand	Base of Slipface	Core	Unknown	No	No
LC24 S15	Hydro Hill-Base	Sand + Silt	Base of Slipface	Core	Unknown	No	No
LC24 S23	Hydro Hill-Base	Dirty Sand	Base of Slipface	Core	Unknown	No	No
LC25 S16	Mrs. B's Farm	Fine tan Sand	Crest of Dune	Core	Dune	Yes	No
LC27 S8	Mrs. B's Farm	Sand	Dune Slope	Core	Dune	Yes	No

SAMPLE	LOCATION	DESCRIPTION	NOTES	SAMPLE COLLECTION METHOD	ENVIRONMENT	H.M. SEP.	XRF
Core Sample Series cont'd...							
LC27A S5	Bumble Bee Hill	Tan Sand	Floor of Pit	Core	Dune?	No	No
LC28 S9	Dunnville	Coarse Sand	Dunnville Industrial Park	Core	Delta	No	Yes
LC28 S12	Dunnville	V. Coarse Sd.	Industrial Park (pebbles + clay)	Core	Delta	No	No
LC27 S17	Dunnville	Coarse Sand	Industrial Park (bedded sand)	Core	Delta	Yes	No
LC28 S20	Dunnville	V. Coarse Sd.	Industrial Park	Core	Delta	No	No
LC29 S13	Garrett Place	V. Coarse Sd.	Dunnville	Core	Delta	No	No
LC29 S14	Garrett Place	V. Coarse Sd.	Dunnville	Core	Delta	Yes	No
LC30 S8	Dunnville	Coarse tan Sd.	"Dead-end Farm"	Core	Delta	No	No
LC31 S11	Dunnville	V. Coarse Sd.	"Dead-end Farm"	Core	Delta	No	No
LC31 S17	Dunnville	V. Coarse Sd.	"Dead-end Farm"	Core	Delta	Yes	Yes
LC32 S12	Jim's Y. High	Fine tan Sd.	Faint bedding	Core	Delta	Yes	No
LC32 S13	Jim's Y. High	Fine tan Sd.	Faint contorted bedding	Core	Delta?	No	Yes
LC33 S16	Gillian Rd.	Wet tan Sd.	Dunnville	Core	Delta?	Yes	No
Odd Samples							
CDP-1	Charles Daley Pk.	Sand	Beach Swash Zone	Grab	Beach	Yes	Yes
KW-2	Kitchener/ Waterloo Sand Pit	Fine Sand	Orig. Collected for H.M.Study	Grab	Unknown	Yes	Yes
SediGraph Experiment	Sample consists of fine portion usually lost from several samples after centrifuging and decanting					No	No

APPENDIX IB: Grain Size Parameters

SAMPLE	% GRAVEL	% SAND	% SILT	% CLAY	MEDIAN	MEAN	SORTING	SKEWNESS	KURTOSIS	MANUAL CALC.?	FREEZE-DRIED?
PD Series											
7A	No grain size analysis										
7B	No grain size analysis										
7C	No grain size analysis										
10A	0	93.50	5.55	0.95	2.76	2.76	0.79	0.02	1.00	No	No
16	No grain size analysis										
17	No grain size analysis										
18	No grain size analysis										
22	4.06	80.23	8.76	6.95	1.18	1.89	2.37	0.63	3.29	No	No
23	7.66	27.89	39.70	24.75	5.86	5.37	3.60	-0.15	0.76	No	No
26	22.40	73.69	2.17	1.75	2.24	1.34	2.14	-0.52	0.68	No	No
28	74.08	24.33	1.15	0.43	-2.85	-2.22	2.05	0.43	0.88	Yes	No
31	20.26	74.50	3.26	1.98	1.46	0.31	2.76	-0.51	2.56	No	No
82	0	92.94	4.43	2.63	2.96	2.98	0.68	0.09	1.24	No	No
129	0	89.42	8.86	1.73	3.26	3.21	0.72	-0.07	1.08	No	No
130	0	91.45	6.71	1.85	2.82	2.79	0.91	-0.01	0.88	No	No
131	0	96.01	2.82	1.16	3.14	3.10	0.54	-0.10	1.06	No	No
132	0	89.03	9.84	1.12	3.27	3.27	0.62	-0.01	1.02	No	No
133	0	94.04	4.59	1.37	3.13	3.13	0.55	0.02	1.03	No	No
134	0	95.37	4.63	0	3.15	3.08	0.48	-0.17	1.02	No	No
135	0	93.29	5.69	1.02	3.06	3.04	0.68	-0.08	1.07	No	No
136	0	94.76	4.16	1.09	3.18	3.16	0.56	-0.09	1.09	No	No
137	0	93.46	5.50	1.04	3.20	3.19	0.58	-0.05	1.03	No	No
138	0	94.54	4.11	1.34	3.26	3.25	0.49	-0.03	1.14	No	No
144	0	94.08	4.74	1.18	3.26	3.26	0.50	-0.03	1.02	No	No
145	0	95.95	2.83	1.23	3.09	3.09	0.52	-0.01	1.02	No	No
146	0	93.68	4.81	1.52	3.15	3.15	0.57	0	1.06	No	No
147	0	93.52	4.97	1.52	3.23	3.23	0.53	0.01	1.03	No	No
148	0	92.97	5.77	1.26	3.23	3.23	0.56	-0.01	1.04	No	No
151	0	94.09	4.97	0.93	3.11	3.10	0.59	-0.03	1.04	No	No
152	0	92.32	6.57	1.11	3.20	3.21	0.58	0.01	0.96	No	No
153	0	95.52	3.26	1.23	3.06	3.05	0.54	-0.03	1.04	No	No
155	0	93.02	5.66	1.33	3.18	3.17	0.62	-0.07	1.03	No	No
158	43.06	56.62	0.14	0.17	-0.60	-0.80	2.03	-0.19	0.91	No	No
160	0	99.43	0.57	0	1.77	1.77	0.47	0.02	1.09	No	No
162	0	97.29	1.96	0.75	2.45	2.47	0.52	0.11	1.089	No	No
166	0.06	92.39	5.87	1.67	2.79	2.79	0.81	0.10	1.50	No	No
175	1.15	84.68	8.70	5.48	2.49	2.67	1.55	0.46	2.51	No	No

SAMPLE	% GRAVEL	% SAND	% SILT	% CLAY	MEDIAN	MEAN	SORTING	SKEWNESS	KURTOSIS	MANUAL CALC.?	FREEZE-DRIED?
PD Series cont'd...											
182	0	93.93	5.05	1.03	2.76	2.80	0.59	0.22	1.31	No	No
183	0	91.09	7.55	1.36	2.77	2.81	0.84	0.30	1.90	No	No
184	0	69.09	29.46	1.45	3.72	3.70	0.75	0.08	1.45	No	No
185	0	74.34	24.31	1.34	3.46	3.57	0.82	0.19	1.43	No	No
186	0	63.49	34.95	1.56	3.73	3.73	0.90	0.15	1.29	No	No
187	0	79.40	19.14	1.46	3.29	3.36	0.93	0.28	1.38	No	No
188	0	64.10	34.26	1.64	3.73	4.02	1.10	0.38	1.34	No	No
189	0	70.85	27.95	1.20	3.54	3.52	0.96	0.09	1.26	No	No
190	0	69.28	28.93	1.79	3.70	3.72	0.77	0.22	1.54	No	No
191	0	88.60	9.74	1.67	2.83	2.92	0.91	0.27	1.29	No	No
192	0.02	10.71	46.71	42.56	7.63	7.45	2.75	-0.06	1.05	No	Yes
193	0	9.04	84.39	6.57	5.69	5.52	1.44	0.03	1.19	No	Yes
194	0	88.56	7.49	3.95	2.78	2.82	1.30	0.30	2.02	No	No
195	0	83.82	11.44	4.74	3.09	3.14	1.32	0.34	2.24	No	No
196	0	80.13	12.24	7.63	3.19	3.33	1.80	0.47	3.25	Yes	Yes
197	0	67.73	19.05	13.22	3.32	4.37	2.64	0.66	1.30	Yes	Yes
198	0	75.84	14.75	9.41	3.23	3.73	2.18	0.58	2.83	Yes	Yes
199	0	81.75	11.42	6.83	3.12	3.19	1.61	0.38	2.66	No	Yes
202	0	91.34	7.52	1.14	2.89	2.90	0.81	0.01	1.08	No	No
218	0	91.87	7.55	0.58	2.73	2.80	0.71	0.22	1.14	No	No
229	0	97.03	1.85	1.12	1.73	1.89	0.75	0.37	1.12	No	No
251	0	91.64	7.03	1.33	2.42	2.53	0.95	0.21	0.94	No	No
255	0	93.73	5.18	1.09	2.77	2.78	0.75	0.06	1.00	No	No
263	0	78.91	19.05	2.05	3.31	3.30	1.09	0.13	1.45	No	No
281	0	91.94	7.20	1.66	2.94	2.96	0.86	0.15	1.40	No	No
282	0	85.40	11.25	3.35	2.96	3.02	1.24	0.31	1.96	No	No
287	0	94.32	5.68	0	3.17	3.09	0.52	-0.15	1.07	No	No
288	0	93.76	4.93	1.31	2.80	2.78	0.77	0	0.99	No	No
289	0	94.99	3.81	1.19	3.05	3.06	0.56	0.02	1.01	No	No
291	0	91.65	7.21	1.14	3.22	3.21	0.61	-0.02	1.02	No	No
292	0	84.22	13.95	1.83	3.34	3.32	0.86	0.05	1.46	No	No
293	0	83.79	14.38	1.83	3.37	3.38	0.75	0.15	1.38	No	No
294	0	93.19	5.14	1.66	2.50	2.52	0.94	0.07	1.05	No	No
295	0	88.97	9.89	1.13	2.92	2.96	0.88	0.11	1.17	No	No
296	0	87.95	10.96	1.09	3.00	3.05	0.81	0.11	1.10	No	No
297	0	94.50	4.63	0.86	2.15	2.23	1.01	0.12	1.01	No	No
303	0	83.21	12.88	3.90	3.00	3.08	1.23	0.32	1.80	No	No
307	0	95.54	3.18	1.28	2.52	2.53	0.74	0.08	0.06	No	No

SAMPLE	% GRAVEL	% SAND	% SILT	% CLAY	MEDIAN	MEAN	SORTING	SKEWNESS	KURTOSIS	MANUAL CALC.?	FREEZE-DRIED?
PD Series cont'd...											
308	0	96.52	2.52	0.95	2.41	2.42	0.69	0.10	1.04	No	No
309	0	89.83	6.64	3.23	2.83	2.87	1.06	0.25	1.67	No	No
311	0	98.00	1.28	0.73	2.18	2.20	0.74	0.05	0.97	No	No
313	0	84.23	4.45	1.33	2.70	2.69	0.82	-0.02	1.01	No	No
314	0	97.95	1.14	0.91	1.99	2.03	0.73	1.10	1.03	No	No
315	0	97.67	1.55	0.78	2.26	2.28	0.74	0.06	0.97	No	No
317	0	89.13	9.45	1.41	2.82	2.88	0.98	0.21	1.37	No	No
318	0	87.00	9.98	3.02	2.82	2.91	1.11	0.31	1.70	No	No
320	0	90.66	7.15	2.19	2.66	2.67	1.01	0.17	1.32	No	No
324	0	88.28	9.86	1.86	2.97	2.99	1.01	0.17	1.48	No	No
325	0	91.04	7.48	1.48	2.79	2.79	0.90	0.03	1.07	No	No
333	1.74	88.41	5.77	4.09	1.72	1.87	1.40	0.47	2.63	No	No
337	0	95.09	3.56	1.34	1.87	1.92	0.81	0.26	1.28	No	No
338	0	97.34	1.58	1.08	2.19	2.23	0.74	0.12	0.96	No	No
339	0	97.54	1.30	1.16	2.53	2.54	0.69	0.05	0.95	No	No
340	0	97.51	1.20	1.29	2.49	2.49	0.71	0.01	1.00	No	No
341	0	47.53	48.01	4.46	4.04	4.40	1.24	0.55	1.72	No	No
342	0	45.00	51.42	3.58	4.08	4.48	1.17	0.54	1.05	No	No
350	0	81.48	15.76	2.76	3.31	3.30	1.02	0.15	1.57	No	No
352	0	90.03	7.16	2.81	2.90	2.97	0.96	0.33	2.33	No	No
357	0	87.17	10.30	2.52	3.09	3.18	0.90	0.41	1.97	No	No
360	0	95.49	3.30	1.21	2.53	2.54	0.82	0.04	1.01	No	No
361	0	92.74	5.51	1.75	2.67	2.68	0.88	0.06	1.00	No	No
364	0	93.55	5.14	1.42	3.12	3.10	0.67	-0.08	1.06	No	No
367	0	91.25	7.25	1.50	3.19	3.17	0.67	-0.03	1.14	No	No
369	0	91.80	6.70	1.50	3.09	3.05	0.76	-0.10	1.07	No	No
372	0	53.09	33.90	13.01	3.94	4.74	2.26	0.69	1.63	Yes	Yes
375	0	78.27	21.70	0	3.52	3.52	0.67	0.02	1.03	No	No
376	0	77.52	18.82	3.66	3.50	3.49	1.07	0.21	2.13	No	No
377	0	76.16	17.96	5.88	3.52	3.53	1.43	0.24	2.88	No	No
379	0	69.18	22.39	8.43	3.66	3.94	1.68	0.48	2.95	No	No
382	0	28.43	53.68	17.89	5.77	5.84	2.48	0.16	1.00	Yes	Yes
386	0	89.75	8.00	2.25	3.06	3.09	0.84	0.19	1.47	No	No
387	0	81.61	12.52	5.87	3.23	3.27	1.49	0.33	2.68	No	No
388	0	93.70	4.24	2.06	2.98	3.01	0.62	0.06	1.06	No	No
390	0	86.70	11.04	2.26	2.93	2.99	1.07	0.22	1.57	No	No
395	0	53.92	37.77	8.30	3.91	4.26	1.74	0.48	1.69	No	No

SAMPLE	% GRAVEL	% SAND	% SILT	% CLAY	MEDIAN	MEAN	SORTING	SKEWNESS	KURTOSIS	MANUAL CALC.?	FREEZE-DRIED?
PD Series cont'd...											
397	0	86.22	11.53	2.25	3.22	3.27	0.79	0.27	1.53	No	No
403	0	95.03	3.85	1.11	2.40	2.43	0.75	0.15	1.07	No	No
408	0	88.92	7.52	3.56	2.85	2.90	1.09	0.26	1.65	No	No
410	0	90.28	7.70	2.02	2.87	2.89	1.00	0.18	1.49	No	No
413	0	77.82	15.45	6.73	3.36	3.40	1.47	0.34	2.59	No	No
414	0	87.33	7.99	4.68	3.20	3.21	1.18	0.30	2.46	No	No
N Series											
02	0	86.43	11.77	1.81	3.04	3.06	1.00	0.15	1.41	No	No
07	6.22	93.19	0.29	0.29	1.05	0.93	0.91	-0.27	2.00	No	No
08	0	86.76	8.93	4.31	1.49	1.87	1.65	0.70	2.39	No	No
09	0	91.18	6.15	2.68	2.48	2.52	1.16	0.21	1.43	No	No
11	2.62	5.33	16.97	74.88	9.69	9.21	3.11	-0.31	1.53	No	Yes
12	0	97.58	1.82	0.60	2.38	2.43	0.44	0.17	1.07	No	No
13	0	98.08	1.14	0.78	2.41	2.43	0.42	0.04	0.97	No	No
16	0	84.28	13.85	1.87	3.31	3.28	0.85	0.07	1.31	No	No
18	0	87.88	8.59	3.53	2.95	2.98	1.11	0.22	1.70	No	No
19	0	88.47	8.07	3.45	2.91	2.94	1.13	0.23	1.70	No	No
22	0	82.71	15.52	1.77	3.21	3.19	1.02	0.11	1.37	No	No
23	0	91.59	6.72	1.69	2.84	2.87	0.78	0.11	1.27	No	No
24	0	45.53	50.26	4.21	4.08	4.47	1.25	0.54	1.09	No	No
25	0	88.34	8.58	3.08	2.75	2.78	1.23	0.27	1.80	No	No
29	0	95.14	3.19	1.67	2.65	2.65	0.60	0.11	1.29	No	No

SAMPLE	% GRAVEL	% SAND	% SILT	% CLAY	MEDIAN	MEAN	SORTING	SKEWNESS	KURTOSIS	MANUAL CALC.?	FREEZE-DRIED?
Core Sample Series											
LC1 S12	0	92.94	5.60	1.46	2.91	2.91	0.70	0.03	1.04	No	No
LC2 S22	0	81.21	17.20	1.59	3.35	3.34	0.87	0.10	1.36	No	No
LC3 S7	0	89.00	7.32	3.68	3.19	3.20	0.95	0.22	1.91	No	No
LC4 S14	0	94.09	4.00	1.91	3.03	3.06	0.53	0.12	1.07	No	No
LC5 S9	0	90.85	6.38	2.77	3.01	2.99	0.91	0.10	1.53	No	No
LC6 S7	0	92.31	4.74	2.95	2.76	2.73	1.02	0.16	1.55	No	No
LC7 S17	0	92.36	5.81	1.83	3.15	3.11	0.72	-0.09	1.01	No	No
LC8 S13	0	92.69	5.32	1.99	2.89	2.90	0.73	0.04	1.20	No	No
LC9 S8	0	85.99	11.75	2.26	3.35	3.37	0.76	0.24	1.65	No	No
LC9 S20	0	85.35	12.35	2.31	3.30	3.31	0.78	0.15	1.36	No	No
LC10 S15	0	90.03	8.79	1.18	3.10	3.14	0.68	0.05	1.01	No	No
LC11 S19	0	76.69	14.64	8.67	3.26	3.33	1.68	0.36	2.45	No	No
LC12 S19	0	37.84	56.05	6.12	5.28	5.05	1.79	-0.02	0.87	No	Yes
LC13 S9	0	72.85	23.40	3.75	3.55	3.48	1.31	0.12	1.98	No	No
LC13 S20	0	56.77	39.30	3.93	3.86	4.21	1.23	0.47	1.55	No	Yes
LC14 S6	0	79.90	12.87	7.22	3.20	3.36	1.50	0.44	2.66	No	No
LC15 S9	0	8.40	51.46	40.45	7.66	8.10	2.65	0.22	1.63	Yes	Yes
LC16 S23	0	94.59	4.28	1.13	2.48	2.53	0.83	0.12	1.01	No	No
LC17 S13	0	92.25	5.02	2.74	2.74	2.77	0.94	0.22	1.50	No	No
LC18 S24	0	90.98	7.62	1.40	2.93	2.92	0.78	0.06	1.17	No	No
LC18 S33	0	40.45	56.34	3.21	4.18	4.50	1.18	0.43	0.01	No	Yes
LC19 S8	0	86.05	12.69	1.26	3.39	3.38	0.63	-0.04	1.17	No	No
LC20 S20	0	84.16	14.77	1.07	3.36	3.36	0.77	0.17	1.38	No	No
LC21 S11	0	84.45	14.02	1.54	3.40	3.41	0.62	0.06	1.12	No	No
LC21 S15	0	68.52	28.48	3.00	3.48	4.05	1.44	0.60	1.50	No	No
LC22 S13	0	88.48	9.57	1.95	3.18	3.21	0.76	0.15	1.26	No	No
LC22 S24	0	84.26	13.41	2.34	3.31	3.31	0.89	0.21	1.58	No	No
LC23 S17	0	84.18	14.13	1.68	3.46	3.42	0.65	-0.08	1.13	No	No
LC23 S22	0	86.70	12.04	1.26	3.37	3.37	0.59	0.03	1.00	No	No
LC23 S29	0	90.52	7.87	1.61	3.02	2.93	0.90	-0.08	1.04	No	No
LC24 S10	0.01	81.47	14.98	3.53	3.26	3.18	1.29	0.08	1.74	No	No
LC24 S13	0	90.83	6.71	2.46	2.44	2.51	1.11	0.33	1.84	No	No
LC24 S15	0	84.43	13.90	1.67	3.18	3.11	1.05	0.02	1.31	No	No
LC24 S23	0	46.46	53.54	0	4.07	4.07	0.62	-0.06	0.77	No	No
LC25 S16	0	92.71	6.19	1.10	2.81	2.80	0.81	0.03	1.05	No	No
LC27 S8	0	77.91	16.81	5.28	3.31	3.37	1.40	0.34	2.18	No	No

SAMPLE	% GRAVEL	% SAND	% SILT	% CLAY	MEDIAN	MEAN	SORTING	SKEWNESS	KURTOSIS	MANUAL CALC.?	FREEZE-DRIED?
<u>Core Sample Series</u> cont'd...											
LC27A S5	0	92.81	6.35	0.84	2.86	2.82	0.83	-0.07	1.05	No	No
LC28 S9	0.02	87.54	12.44	0	1.76	1.97	1.04	0.44	1.53	No	No
LC28 S12	1.51	84.19	6.37	7.93	1.71	2.02	2.04	0.54	3.06	No	No
LC27 S17	0	94.89	4.33	0.78	2.86	2.92	0.55	0.15	1.29	No	No
LC28 S20	3.04	90.44	5.26	1.26	1.59	1.63	1.06	0.20	2.11	No	No
LC29 S13	0.15	95.11	3.09	1.64	2.20	2.19	0.85	0.07	1.09	No	No
LC29 S14	0.12	93.60	4.20	2.09	2.00	2.03	1.06	0.16	1.10	No	No
LC30 S8	0	92.14	5.88	1.97	2.31	2.42	1.06	0.36	1.55	No	No
LC31 S11	0.48	92.93	5.76	0.83	1.73	1.81	0.90	0.39	2.18	No	No
LC31 S17	0.22	96.25	5.52	1.02	1.29	1.30	0.70	0.14	1.52	No	No
LC32 S12	0	88.27	9.18	2.55	3.07	3.15	0.88	0.46	2.38	No	No
LC32 S13	0	87.63	9.50	2.87	3.03	3.14	0.91	0.53	2.32	No	No
LC33 S16	0	90.49	6.90	2.60	2.72	2.76	1.05	0.25	1.56	No	No
<u>Odd Samples</u>											
CDP-1	8.40	90.91	0.20	0.39	0.58	0.46	0.93	-0.22	1.45	No	No
KW-2	0	86.93	12.50	0.57	3.17	3.25	0.61	0.29	0.99	No	No
SediGraph Experiment	0	0	12.12	87.88	12.30	11.75	2.82	-0.30	1.28	Yes	No

APPENDIX II - FREEZE-DRYING COMPARISON

Sample No.	% SILT			% CLAY			MEDIAN (in phi units)			MEAN (in phi units)		
	Freeze-Dried	Not Freeze-Dried	Difference	Freeze-Dried	Not Freeze-Dried	Difference	Freeze-Dried	Not Freeze-Dried	Difference	Freeze-Dried	Not Freeze-Dried	Difference
PD 192	46.71	47.71	1.000	42.56	41.56	-1.000	7.63	7.51	-0.12	7.45	7.51	0.06
PD 193	84.39	83.48	-0.910	6.57	7.48	0.910	5.69	5.72	0.03	5.52	5.57	0.05
PD 196*	12.24	12.998	0.758	7.63	6.876	-0.754	3.19	3.21	0.02	3.33	3.33	0
PD 197*	19.05	19.24	0.190	13.22	13.03	-0.190	3.32	3.31	-0.01	4.37	4.30	-0.07
PD 198*	14.75	16.31	1.560	9.41	7.85	-1.560	3.23	3.22	-0.01	3.73	3.58	-0.15
PD 199	11.42	11.73	0.310	6.83	6.52	-0.310	3.12	3.12	0	3.19	3.19	0
PD 372*	33.903	33.290	-0.613	13.008	13.620	0.612	3.94	3.96	0.02	4.74	4.78	0.04
PD 382*	53.682	54.280	0.598	17.886	17.288	-0.598	5.77	5.80	0.03	5.84	5.82	-0.02
N-11	16.97	17.42	0.450	74.88	74.42	-0.460	9.69	9.71	0.02	9.21	9.48	0.27
LC12 S19	56.05	56.18	0.130	6.12	5.98	-0.140	5.28	5.39	0.11	5.05	5.08	0.03
LC13 S20	39.30	39.28	-0.020	3.93	3.95	0.020	3.86	3.86	0	4.21	4.16	-0.05
LC15 S9*	51.16	51.16	0	40.45	40.44	-0.010	7.66	7.65	-0.01	8.10	8.14	0.04
LC18 S33	56.34	56.33	-0.010	3.21	3.23	0.020	4.18	4.18	0	4.50	4.48	-0.02
	"Difference" Data: Sum = 3.443, Average = 0.265, Range = +1.560 to -0.910			"Difference" Data: Sum = -3.460, Average = -0.266, Range = +0.910 to -1.560			"Difference" Data: Sum = 0.08, Average = 0.006, Range = +0.11 to -0.12			"Difference" Data: Sum = 0.18, Average = 0.014, Range = +0.27 to -0.15		

(Cont'd)

APPENDIX II - FREEZE-DRYING COMPARISON (Cont'd)

Sample No.	SORTING VALUES (in phi units)			SKEWNESS VALUES			KURTOSIS VALUES		
	Freeze-Dried	Not Freeze-Dried	Difference	Freeze-Dried	Not Freeze-Dried	Difference	Freeze-Dried	Not Freeze-Dried	Difference
PD 192	2.750	2.700	-0.050	-0.060	-0.040	0.020	1.050	1.010	-0.040
PD 193	1.440	1.480	0.040	0.030	0.050	0.020	1.190	1.150	-0.040
PD 196*	1.804	1.640	-0.164	0.474	0.437	-0.037	3.253	2.851	-0.402
PD 197*	2.642	2.588	-0.054	0.664	0.663	-0.001	1.299	1.413	0.114
PD 198*	2.179	1.898	-0.281	0.580	0.519	-0.061	2.832	2.490	-0.342
PD 199	1.61	1.64	0.030	0.380	0.390	0.010	2.660	2.720	0.060
PD 372*	2.262	2.256	-0.006	0.689	0.689	0	1.628	1.539	-0.089
PD 382*	2.477	2.391	-0.086	0.158	0.121	-0.037	0.999	0.950	-0.049
N-11	3.110	3.370	0.260	-0.310	-0.180	0.130	1.530	1.48	-0.050
LC12 S19	1.790	1.730	-0.060	-0.02	-0.10	-0.080	0.870	0.820	-0.050
LC13 S20	1.230	1.150	-0.080	0.470	0.430	-0.040	1.550	1.430	-0.120
LC15 S9*	2.649	2.563	-0.086	0.218	0.223	0.005	1.634	1.577	-0.057
LC18 S33	1.180	1.130	-0.050	0.430	0.400	-0.030	1.010	0.990	-0.020
	"Difference" Data: Sum = -0.587, Average = -0.045, Range = +0.260 to -0.281			"Difference" Data: Sum = -0.101, Average = -0.008, Range = +0.130 to -0.080			"Difference" Data: Sum = -1.085, Average = -0.083, Range = +0.144 to -0.402		

(Cont'd)

APPENDIX II - FREEZE-DRYING COMPARISON (Cont'd)

Notes: 1) * = values were calculated by hand

2) difference = (Not Freeze-dried Value) - (Freeze-dried Value)

This exercise shows:

Freeze-drying "breaks up" silt particles slightly to form marginally more clay-sized particles. (circa + 0.3%). This is not enough to noticeably alter the skewness.

The till grain size analyses of this thesis (ie. N-11) are probably unreliable, because of their high silt and clay content, but in most cases, freeze-drying makes no significant difference in the grain size statistics. However, the following information establishes limits of accuracy:

Silt and clay data are accurate to within ± 2%
Median data are accurate to within ± 0.15 phi
Mean data are accurate to within ± 0.30 phi
Sorting data are accurate to within ± 0.30 phi
Skewness data are accurate to within ± 0.15
Kurtosis data are accurate to within ± 0.40

Freeze-dried values were used for plotting and mapping.

APPENDIX III - ORIGINAL/REPEAT COMPARISONS

Sample No.	% SAND			% SILT			% CLAY			MEDIAN (phi values)		
	Original Value	Repeat Value	Difference	Original Value	Repeat Value	Difference	Original Value	Repeat Value	Difference	Original Value	Repeat Value	Difference
PD 10A	93.50			5.55			0.95			2.76		
PD 10B		94.12	-0.62		4.96	0.59		0.92	0.03		2.76	0
PD 10C		93.77	-0.27		5.30	0.25		0.94	0.01		2.78	-0.02
PD 10D		93.98	-0.48		5.06	0.49		0.96	-0.01		2.77	-0.01
PD 82	92.94	92.94	0	4.43	4.75	-0.32	2.63	2.31	0.32	2.96	2.96	0
PD 138	94.54	93.01	1.53	4.11	5.48	-1.37	1.34	1.51	-0.17	3.26	3.26	0
PD 144	94.08	93.60	0.48	4.74	4.93	-0.19	1.18	1.47	-0.29	3.26	3.28	-0.02
PD 182	93.93	93.41	0.52	5.05	5.30	-0.25	1.03	1.29	0.26	2.76	2.78	-0.02
PD 188	64.10			34.26			1.64			3.73		
PD 188-R1		64.10	0		33.85	0.41		2.05	-0.41		3.73	0
PD 188-R2		64.10	0		34.16	0.10		1.74	0.10		3.73	0
PD 188-R3		64.10	0		33.85	0.41		2.05	-0.41		3.73	0
PD 192	10.71	10.72	-0.01	46.71	46.07	0.64	42.56	43.22	-0.66	7.63	7.58	0.05
PD 288	93.93	93.62	0.31	4.93	5.20	-0.27	1.31	1.18	0.13	2.80	2.81	-0.01
PD 408	88.92	88.94	-0.02	7.52	7.91	-0.39	3.56	3.15	0.41	2.85	2.85	0
N-08-R1	91.18			6.15		0.01	2.68			2.48		
N-08-R2		91.18	0		6.14	0.01		2.69	0.01		2.48	0
N-08-R3		91.18	0		6.15	0		2.68	0		2.48	0
N-08-R4		91.18	0		5.93	0.22		2.89	-0.21		2.48	0
N-08-R5		91.18	0		6.15	0		2.68	0		2.48	0
LC4 S14	94.09	94.09	0	4.00	3.98	0.02	1.91	1.93	-0.02	3.03	3.03	0
LC7 S17	92.36	92.36	0	5.79	5.81	-0.02	1.85	1.83	0.02	3.15	3.15	0
LC13 S20*	56.77	59.61	-2.84*	39.30	37.96	1.34	3.93	2.43	1.50*	3.86	3.81	0.05
LC19 S8	86.05	85.27	0.78	12.69	13.65	-0.96	1.26	1.08	0.18	3.39	3.43	-0.04
LC32 S12	88.27	86.34	1.93	9.18	10.93	-1.75	2.55	2.73	-0.18	3.07	3.11	-0.04
	"Difference" Range: 1.93 to -2.84*			"Difference" Range: +1.34 to -1.75			"Difference" Range: +1.5-* to -0.66			"Difference" Range: +0.05 to -0.04		

(Cont'd)

APPENDIX III - ORIGINAL/REPEAT COMPARISONS (Cont'd)

Sample No.	MEAN (phi values)			SORTING (phi values)			SKEWNESS			KURTOSIS		
	Original Value	Repeat Value	Difference	Original Value	Repeat Value	Difference	Original Value	Repeat Value	Difference	Original Value	Repeat Value	Difference
PD 10A	2.76			0.79			0.02			1.00		
PD 10B		2.75	0.01		0.76	0.03		0.00	0.02		0.99	0.01
PD 10C		2.78	-0.02		0.78	0.01		0.00	0.02		0.97	0.03
PD 10D		2.77	-0.01		0.77	0.02		0.01	0.01		0.97	0.03
PD 82	2.98	2.98	0	0.68	0.68	0	0.09	0.09	0	1.24	1.25	-0.01
PD 138	3.25	3.27	-0.02	0.49	0.52	-0.03	-0.03	0.03	-0.06	1.14	1.08	0.06
PD 144	3.26	3.28	-0.02	0.50	0.51	-0.01	-0.03	-0.02	-0.01	1.02	1.02	0
PD 182	2.80	2.83	0.03	0.59	0.60	-0.01	0.22	0.23	-0.01	1.31	1.34	-0.03
PD 188	4.02			1.10			0.38			1.34		
PD 188-R1		4.04	-0.02		1.13	-0.03		0.40	-0.02		1.39	-0.05
PD 188-R2		4.04	-0.02		1.12	-0.02		0.39	-0.01		1.34	0
PD 188-R3		4.01	0.01		1.10	0		0.38	0		1.36	-0.02
PD 192	7.45	7.52	-0.07	2.75	2.84	-0.09	-0.06	-0.01	-0.05	1.05	1.01	0.04
PD 288	2.78	2.80	-0.02	0.77	0.77	0	0.00	0.00	0	0.99	0.98	0.01
PD 408	2.90	2.90	0	1.09	1.04	0.05	0.26	0.23	0.03	1.65	1.54	0.11
N-08-R1	2.52			1.17			0.22			1.45		
N-08-R2		2.52	0		1.15	0.02		0.21	0.01		1.42	0.03
N-08-R3		2.52	0		1.16	0.01		0.21	0.01		1.43	0.02
N-08-R4		2.52	0		1.17	0		0.22	0		1.47	-0.02
N-08-R5		2.52	0		1.16	0.01		0.21	0.01		1.43	0.02
LC4 S14	3.06	3.06	0	0.53	0.53	0	0.12	0.12	0	1.07	1.07	0
LC7 S17	3.11	3.11	0	0.72	0.72	0	-0.09	-0.09	0	1.01	1.01	0
LC13 S20*	4.21	4.15	0.06*	1.23	1.13	0.10*	0.47	0.45	0.02	1.55	1.29	0.40*
LC19 S8	3.38	3.41	-0.03	0.63	0.62	0.01	-0.04	-0.07	0.03	1.17	1.15	0.02
LC32 S12	3.15	3.22	-0.07	0.88	0.93	-0.05	0.46	0.49	-0.03	2.38	2.30	0.08
	"Difference" Range: +0.06* to -0.07			"Difference" Range: +0.10* to -0.09			"Difference" Range: +0.03 to -0.06			"Difference" Range: +0.40* to -0.05		

(Cont'd)

APPENDIX III - ORIGINAL/REPEAT COMPARISONS

Notes: * = Sample has some values that are fairly extreme.
Use range values with caution.

Original values were used in plotting and mapping.

Confidence Limits:

Sand % data are accurate to ± 3.0%
Silt % data are accurate to ± 2.0%
Clay % data are accurate to ± 2.0%
Median data are accurate to ± 0.1 phi
Mean data are accurate to ± 0.1 phi
Sorting data are accurate to ± 0.1 phi
Skewness data are accurate to ± 0.1
Kurtosis data are accurate to ± 0.15

(Kurtosis confidence limit excludes effect of extreme value obtained)

APPENDIX IV:
Field and Laboratory Methods

Sampling:

Vertical channel sampling was employed when the texture of the sediment changed significantly over small distances, such as alternating coarse/fine beds, or when lenses of coarse-grained material appeared scattered through a generally fine-grained exposure. In areas without adequate exposure, random spot sampling was used. A pit 0.5 to 1.0 metre deep was dug and a sample was taken at the bottom. Systematic spot sampling was applied in cases where an exposure afforded a wide variety of textures (such as the "Horse Farm" site) or the exposure appeared fairly homogeneous. In the former case, individual beds were sampled. In the latter, a series of evenly spaced samples was taken over a vertical interval.

Coring Technique:

Coring technique follows that of R. Dalrymple (1980 personal communication), who obtained his information on coring equipment and design from Phillips (U.S.G.S., Menlo Park, California), who modified it from plans published by Sanders (1968). The coring equipment used for this investigation bears little resemblance to Sander's corer, but the method remains essentially the same.

After the general area of interest for coring was selected, a coring site was chosen that was sufficiently far away from trees so as to minimize the possibility of encountering a root while coring. Two-metre lengths of 3 inch inside diameter ABS pipe (1/4 inch wall thickness) were used as core tubes. Preliminary preparation of the tubing included insuring that both ends were cut at 90° to the long axis of the pipe, for a flat contact with the rest of the coring equipment, and bevelling one end of the pipe to ease penetration into the sediment and to reduce the distortion effect that may be caused by lateral compaction of the sediments while being forced into the tube. An attempt was made to start the core penetration by hand in as vertical position as possible. Gentle tapping of the weight usually initiated enough penetration to allow the coring tube to support the rest of the equipment. The exceptions occurred when attempting to penetrate clay, in which case additional support and increased force of pounding were necessary. The amount of time and effort necessary to achieve total penetration of the coring tube depended on the composition of the sediment. Ideally, the material to be cored should be water-saturated such that the particles of sediment are easily displaced by the coring tube during penetration. Water also provides some lubrication during extraction of the coring tube. Greater water content and coarser sand texture permitted faster penetration, while dry sediments with a high clay content slowed progress considerably. Two operators were always necessary while coring.

Once full penetration was achieved, any variance of the core tube from vertical was noted as well as the core's orientation to north and its identifying number. Inside and outside depths to ground surface were then measured to determine degree of compaction. Enough water was poured inside the tube to fill it to the rim. A few moments were taken to allow at least the top part of the core to become saturated with water. The water provided an air seal during extraction of the core, as well as displacing the air above the sediment, so that, after full sealing and commencement of extraction, a vacuum was produced such that the sediment within the tube and the tube itself acted as a single "piston" while being raised, rather than allowing sediment to fall out of the open end.

Extraction of the tube from the ground was achieved by attaching the extraction handles and either pulling up by hand or, as was most common, pulling up with the assistance of one or two car jacks. The jacks were placed either directly in contact with the handles, or a chain was wrapped around the core tube and attached to the jack. When sufficient friction was overcome to loosen the tube from the ground, the tube was then extracted the rest of the way by hand. As soon as the bottom end of the tube cleared the ground surface, a plastic cap was placed over it to prevent loss of core. The top cap was then removed and the excess water poured off. The tube was transported to the lab in as vertical position as possible. Once in the lab, the bottom cap of the coring tube was loosened to allow any excess water to drain out. This usually took 2 to 3 days.

In a limited number of cases, a total of approximately four metres of sediment was obtained at a single coring site by extracting the 2 metre core, and carefully placing a 4 metre tube down the hole left by the removal of the 2 metre core. Pounding of the new tube then proceeds as before.

Extraction and transport of these 4 metre cores was difficult, so their use was limited, but when the two cores from one site were put end to end in the lab, a fair representation of a 3 to 4 metre core was obtained.

Equipment breakdown:

As a result of the pounding nature of the coring method, it was inevitable that parts of the coring equipment would eventually fail. This was due to the stress caused by the intense shock of the weight hitting the steel cap. The most common failure was the breaking of the weld holding the guide pipe to the steel cap. While working with Dalrymple in the field, the same problem was encountered, but virtually nothing could be done to avoid it. Dalrymple (1983, personal communication) reports that in a recent attempt to overcome the problem, very large rivets were used to attach the guide pipe to the steel cap, but these also eventually broke under the force of the blows.

During the field work for this investigation, the original weld remained intact for the completion of thirteen cores. After the first repair at the Brock University machine shop, subsequent welds lasted for only 2 or 3 cores, and the equipment would occasionally have to be repaired in the field at a local garage. The additional welding performed after the first breakdown weakened the fabric of the steel, making it fairly brittle and subject to additional failure. Consequently, a fair amount of field time was lost waiting for equipment repair.

A change of design may have helped this breakage problem. If the steel cap and guide pipe could be made out of a single piece of metal, thus avoiding any welding, increased strength could be expected. Also, if the guide pipe could be made out of solid steel rod instead of a hollow pipe, it would be much less susceptible to failure. Recent advances in coring unconsolidated sediments by means of vibracoring would eliminate the problem altogether, since no pounding of the core tube is necessary. The prohibitive cost of a vibracoring setup makes the equipment that was used for this thesis cost effective in terms of materials. However, cores are limited to approximately 2 metres length. Much of the frustration due to excess repair time could be eliminated as long as "difficult-to-core" materials, such as compacted sand or massive clay, are avoided, thus easing the strain on the coring equipment.

Cutting and Sampling of Cores

Extraction of the sediment from the core tube with internal structures undisturbed proved impossible. Experiments with dry, wet and frozen cores were conducted, all with negative results. Therefore, the core tubes had to be cut open for examination and subsampling. A core cutting rack was constructed which allowed the core tube, in a horizontal position, to be cut by a portable power saw. A track for the saw was designed to allow the saw to cut only the core tube wall, and not penetrate the sediment within. The track also allowed two straight cuts along the long axis of the tube to be made 180° apart. Standard procedure adopted was to cut the core tube along the east-west plane, and to subsample the north half of the core. The north half was usually sliced into 5 cm long segments and each subsample was described and bagged separately, noting its depth in the core. Subsamples less than 5 cm long were taken wherever a marked change in sediment character was seen. Any features seen in the E-W plane were also described at the time of subsampling. Occasionally, when a massive section of core, or one with potentially limited use was encountered, alternate 5 cm long segments were discarded to reduce the total number of samples.

In cores with a high clay content, piano wire was used to split the core along the E-W plane prior to sampling. This gave a much smoother surface from which to make peels.

All sampling tools were cleaned between samples in order to avoid cross contamination. Core samples were then handled the same as surface samples.

Core Peel Technique

After sampling, the south half of each core was air-dried in a fume hood for at least one day, after which, the E-W surface was planed smooth with a straight edge and loose sand was gently blown away. The cut surface of the core tube was coated with Vaseline

to prevent excess glue from forming a bond between the masonite and the core tube.

Common peel procedure for unconsolidated sediment involves the use of epoxy resin. This material proved too costly and difficult to obtain, and many alternate substances were experimented with, including paraffin wax, epoxy floor sealer, Plasticast casting resin, an alternate epoxy resin, fiberglass plastic filler, and LePage's Bondfast glue. Only the Bondfast was inexpensive, widely available, easy to clean-up and had the proper soaking and hardening properties for my use.

In order to make a peel of a core, diluted Bondfast (2 parts water to 1 part glue) was poured on the dry, smooth surface of the core and quickly and gently brushed to wet the entire surface evenly. Experience determined the amount of glue necessary to soak into the sediment the proper depth (approximately 1 cm). The coated core was then allowed to dry in a fume hood until the glue surface was firm enough to withstand the application of thick, undiluted Bondfast. Two coats of full strength Bondfast were then applied by brushing, allowing time for full drying between coats. At some point in the process, photos were taken of the cores to ensure some record of the structures in case the peeling process was not successful.

When the glue was completely dry (after 2 to 3 days in a fume hood) the peel was separated from the core tube wall, the entire core was inverted over a strip of masonite, and the core tube was lifted off the peel and excess sediment. Since the interior part of the excess sediment, including the detailed peel surface, was still damp, the peel and excess sediment were left undisturbed for another 2 days. At this point, the peel was hard enough to carefully brush off and discard excess sediment from the detailed peel surface. Once the peel was free of most loose sand, it was glued to the masonite strip and labelled. Since the peel is a negative "image" of the south half of the core, when looking at a peel, west is generally to the left and east is generally to the right (See photos of peels, Plates 5 to 11).

Sedigraph Analysis:

A brief summary of the theory and operation of the SediGraph machine is included here. The concentrated slurry from wet sieving was placed in a small beaker with a magnetic stirring bar. While constantly being stirred, a continuous aliquoit of suspension was pumped into a clear-walled cell. When all parameters for analysis had been optimized, the pumping was stopped and the sediment began to settle in the cell. A small X-ray beam was positioned to pass through the bottom of the cell. As the analysis progressed, the cell was lowered through the X-ray beam at an exponentially decreasing rate, while a detector on the opposite side of the cell measured the intensity of X-ray energy passing through it. The intensity of energy passing through the cell at any one point is representative of the amount of sediment particles interrupting the X-ray beam. Since the sediment cell is being moved downward at a known rate, the size of particles interrupting the X-ray beam at any one point is known from Stoke's law. The computation module of the SediGraph receives the cell movement and X-ray intensity information and feeds a continually-computed value to a recording device, where a graph is produced (Fig. 52). This graph represents particle size measured, versus relative amount present. Relative values are converted to absolute amounts of any particle size from the calculated total amounts of fines present in the "100 gram subsample" (after Micromeritics Instrument Corp., 1978).

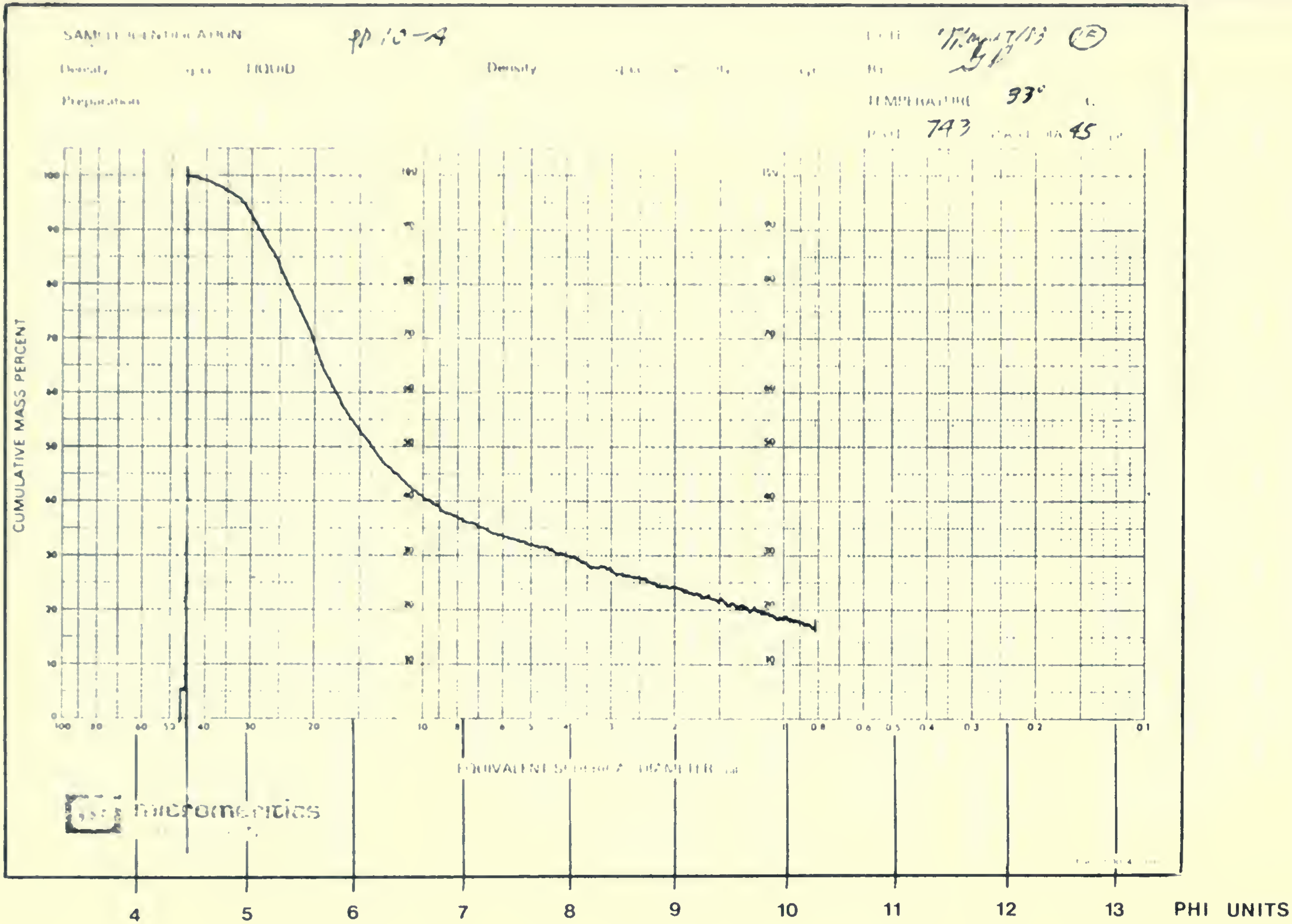


Figure 52: Typical Graph Produced by SediGraph

Statistical Parameter Graphs

For many years, geologists and sedimentologists have been attempting to interpret and/or predict clastic depositional environments from bivariate plots of grain size distribution statistics. This has met with varying degrees of success. The reader is referred to papers by Friedman (1961), Folk and Ward (1957), Folk (1966) and Jones (1970), for examples using different statistics formulae.

The author employed one statistical graphing method in an attempt to delineate the environments of deposition of the thesis samples. The chosen method, bivariate plots of Folk and Ward graphic statistics, was used to gain insight as to the general nature of the sediments and their possible relationships to one another.

Mason and Folk (1958) found that a plot of skewness versus kurtosis was the best bivariate graph to distinguish between the beach, dune and aeolian flat environments of Mustang Island, Texas. They used the graphic parameters set out by Folk and Ward (1957). The fact that Mason and Folk were able to "readily distinguish" the different environments of the island, even though the samples were "exceedingly uniform", suggests that an examination of the Folk and Ward parameters for samples in the Dunnville area is in order, since it appeared that the units sampled in the thesis area may be difficult to distinguish, particularly on grain size statistics alone.

Another frequently used method of calculating grain size parameters is the method of moments (Friedman, 1961). Whereas the complete size distribution curve is taken into consideration to compute moment measures, graphic methods discard the tails of distribution curves to a varying extent, depending on the method used. Contrastly, when using moment measures, the finest fraction is frequently lumped into one class, or the distribution is sometimes artificially "closed" by extrapolation towards the fines. Moment skewness and kurtosis are likely to be affected by such procedures, though graphic measures are not (Folk, 1966).

In his paper comparing both moment and graphic statistics, Jones (1970) concludes that the moment measures have desirable statistical properties if there are no errors induced by grouping of data or truncation (open-endedness) of the grain-size distribution. Jones explains that the grouping error will be unimportant if the sieve interval is small compared to the sorting of the sample. Also, truncation errors are significant if truncation makes up as much as one percent of the sample. Jones (1970) also states that even if there are no errors introduced by grouping or truncation, the sample moments are slightly biased.

With regards to statistics derived by graphic methods, Jones (1970) states that:

"The graphical estimations use less of the sample data than do the moment measures, and are therefore less efficient, implying greater variability. An additional source of variation is due to interpolation of percentiles from the cumulative curve, although this is relatively minor. A more serious problem is that the graphic statistics are inter-related; skewness and kurtosis in the sample will alter the estimates of population mean, sorting, skewness and kurtosis."

Jaquet and Vernet (1976) conclude that mean, sorting and skewness could be estimated either by moment measures or by Folk and Ward's methods, without substantial differences in interpretation. They also conclude that in the determination of kurtosis, both methods have disadvantages; moment kurtosis does not provide much more information than standard deviation, and the graphic kurtosis depends, to a great extent, on skewness.

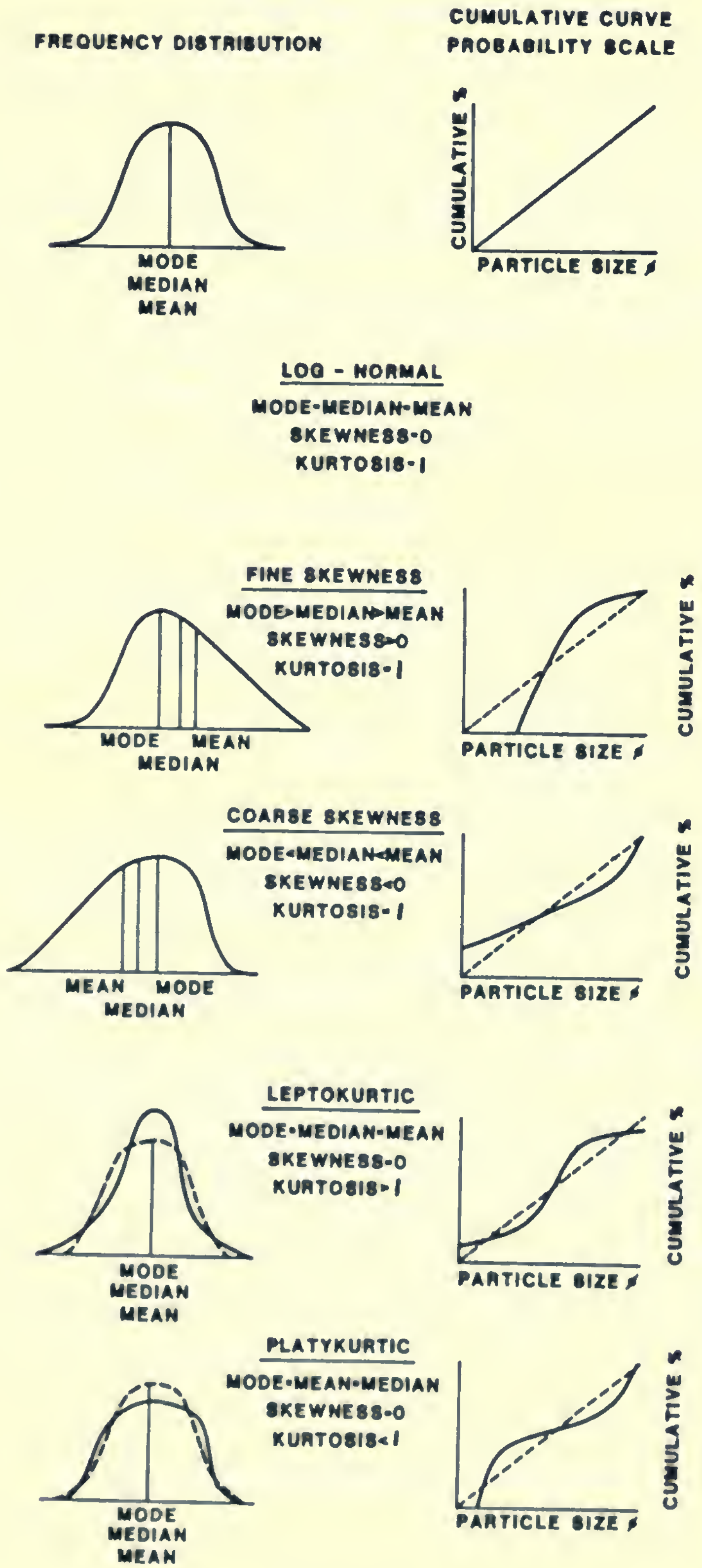
Since the grain size analysis computer program used for this thesis computed both Folk and Ward statistics and moment measures, it was decided to select several analyzed samples and do a random comparison of values obtained; ie.: the Moment Mean with the Graphic (Folk and Ward) Mean, Moment Skewness with Graphic Inclusive Skewness, etc. The results are depicted in Figures 37 to 40. These graphs demonstrate that one must be very careful when comparing any generated plots to plots published in the literature, especially with regards to which method was used to calculate the statistics. It is clear that, depending on which

method is used, vastly different numbers could be generated, possibly resulting in misinterpretation of plotted values. It appears that this is not unknown in the literature, where an author has tried to compare his Folk and Ward statistical plots with graphs produced by Friedman (1961). For instance, Moiola and Weiser (1968) clearly state that they used the formulas of Folk and Ward (1957) in calculating the grain size statistics for their samples, but then they proceed to compare their plotted samples with Friedman's (1961) graphs. As might be expected, they achieved mixed results.

Figure 53:

TYPES OF PARTICLE SIZE DISTRIBUTION

(after Petro-Canada Research and Development, Calgary)



APPENDIX V

Carbon-14 Analysis

BROCK UNIVERSITY

DEPARTMENT OF GEOLOGICAL SCIENCES

REQUEST FOR RADIOCARBON AGE DETERMINATION

Field sample No.: PEAT GP1 Brock Univ. No.: Date submitted: APR. 6/82

Collector: G.P. PASTIRIK Date collected: APR 2/82

Material: SANDY PEAT OR ORGANIC-RICH SAND Enclosing Material: MED-COARSE SAND (TOP?) BLUE CLAY (BOTTOM?)

Geographic Location (include Lat. & Long.; attach sketch if useful)

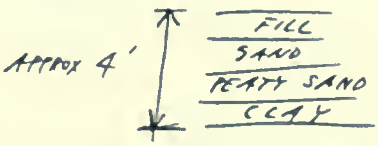
42° 54' 55"
79° 36' 53"
NEW SUBDIVISION N. OF DUNNVILLE, ONTARIO

Collection site (road cut, borehole, etc.; depth or position on bank; distance behind natural exposed face; exposure fresh, old, plant growth? enclosing material wet, dry, oxidized, etc.? attach sketch):

- HOUSE EXCAVATION
- NOT INSITU – PEAT BOULDER DUG FROM PILE OF EXCAVATED MATERI
- FRESH EXPOSURE
- PROBABLY 2 - 4' BELOW SURFACE
- MODERN ROOTS
- BLOCK MOIST BUT VERY FIRM
- ENCLOSING MATERIAL MOIST – SOME OXIDATION

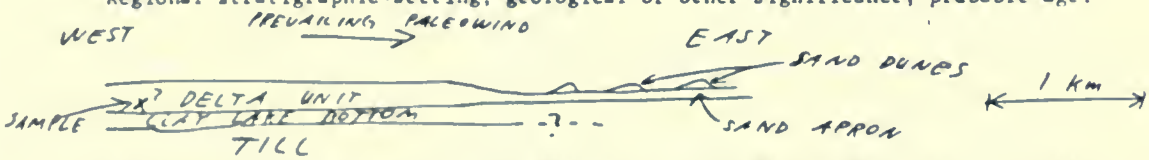
Local stratigraphic relations (attach sketch):

POSTULATED GENERAL RELATIONS:



POSSIBLY INCORPORATED WITHIN "DELTA UNIT", OVER CLAY GLACIAL LAKE BOTTOM, OVER TILL.

Regional stratigraphic setting; geological or other significance; probable age:



State of preservation; factors that may result in anomalous age (present or past geological environment; sampling, storage, etc.):

AFTER MAT'L EXCAVATED, PILED + BURIED FOR UNKNOWN TIME (PROBABLY CIRCA SUMMER 1981 TO SPRING 1982); WHEN DUG UP, PLACED IN BLACK GARBAGE BAG FOR TRANSPORT + AIR DRIED IN LAB. MODERN ROOTS PRESENT, CARBONATE SAND PARTICLES PROBABLE

References to pertinent published information or to previous radiocarbon dates:

FEENSTRA, 1972, QUATERNARY GEOLOGY OF THE DUNNVILLE AREA, ONT. DIV. MINES, PRELIM. MAP P. 981 SCALE 1:50,000

Copy of Original Radiocarbon Request Form

(Cont'd)

BROCK UNIVERSITY GEOLOGICAL SCIENCES

RADIOCARBON LAB

SAMPLE NO: OURS BGS 795

THEIRS Peat G P 1

SAMPLE DESCRIPTION George Pastirik Thesis

PRETREATMENT

	Yes	No
(a) Removal of foreign material	X	
(b) Removal of humic acid		X
(c) Distilled water wash	X	
(d) Acid leach		X

(e) Comments

Rootlets removed, sample washed, dried

burned 70 gm

Benzene Produced: 3.4150 g

Counting Time: 3000 min

Number of Disintegration 144,000

CALCULATED AGE: 225 ± 100 yrs

Date Sample analysed: April 20, 1982.

Technician: H. Melville

Copy of Radiocarbon Laboratory Results

APPENDIX VI

Useful Charts and Tables

Table 3: Phi Comparison Table (Folk, 1974)

U. S. Standard Sieve Mesh #		Millimeters	Microns	Phi (φ)	Wentworth Size Class	
				-20		
		4096		-12		
		1024		-10	Boulder (-8 to -12φ)	
Use		256		-8		
wire		64		-6	Cobble (-6 to -8φ)	GRAVEL
squares		16		-4	Pebble (-2 to -6φ)	
5		4		-2		
6		3.36		-1.75		
7		2.83		-1.5	Granule	
8		2.38		-1.25		
10		2.00		-1.0		
12		1.68		-0.75		
14		1.41		-0.5	Very coarse sand	
16		1.19		-0.25		
18		1.00		0.0		
20		0.84		0.25		
25		0.71		0.5	Coarse sand	
30		0.59		0.75		
35	1/2	0.50	500	1.0		
40		0.42	420	1.25		
45		0.35	350	1.5	Medium sand	SAND
50		0.30	300	1.75		
60	1/4	0.25	250	2.0		
70		0.210	210	2.25		
80		0.177	177	2.5	Fine sand	
100		0.149	149	2.75		
120	1/8	0.125	125	3.0		
140		0.105	105	3.25		
170		0.088	88	3.5	Very fine sand	
200		0.074	74	3.75		
230	1/16	0.0625	62.5	4.0		
270		0.053	53	4.25		
325		0.044	44	4.5	Coarse silt	
		0.037	37	4.75		
	1/32	0.031	31	5.0		
	1/64	0.0156	15.6	6.0	Medium silt	MUD
	1/128	0.0078	7.8	7.0	Fine silt	
	1/256	0.0039	3.9	8.0	Very fine silt	
		0.0020	2.0	9.0		
		0.00098	0.98	10.0	Clay	
		0.00049	0.49	11.0	(Some use 12φ or	
		0.00024	0.24	12.0	9φ as the clay	
		0.00012	0.12	13.0	boundry)	
		0.00006	0.06	14.0		

Table 4: Folk and Ward Grain Size Statistics - Verbal Scales

MEAN(M_Z):

phi units	Wentworth Scale
-2 to -1	granule
-1 to 0	very coarse sand
0 to 1	coarse sand
1 to 2	medium sand
2 to 3	fine sand
3 to 4	very fine sand
4 to 5	coarse silt
5 to 6	medium silt
6 to 7	fine silt
7 to 8	very fine silt
8 to 9	clay
> 9	clay

SORTING: (Inclusive Graphic Standard Deviation, in phi units) ($_I$)

0.00 to 0.35	very well sorted
0.35 to 0.50	well sorted
0.50 to 1.00	moderately sorted
1.00 to 2.00	poorly sorted
2.00 to 4.00	very poorly sorted
> 4.00	extremely poorly sorted

SKEWNESS: (Inclusive Graphic Skewness) (Sk_I)

-1.00 to -0.30	very negatively skewed
-0.30 to -0.10	negatively skewed
-0.10 to +0.10	nearly symmetrical
+0.10 to +0.30	positively skewed
+0.30 to +1.00	very positively skewed

KURTOSIS: (Graphic Kurtosis) (K_G)

0.00 to 0.67	very platykurtic
0.67 to 0.90	platykurtic
0.90 to 1.11	mesokurtic (nearly normal)
1.11 to 1.50	leptokurtic
1.50 to 3.00	very leptokurtic
> 3.00	extremely leptokurtic

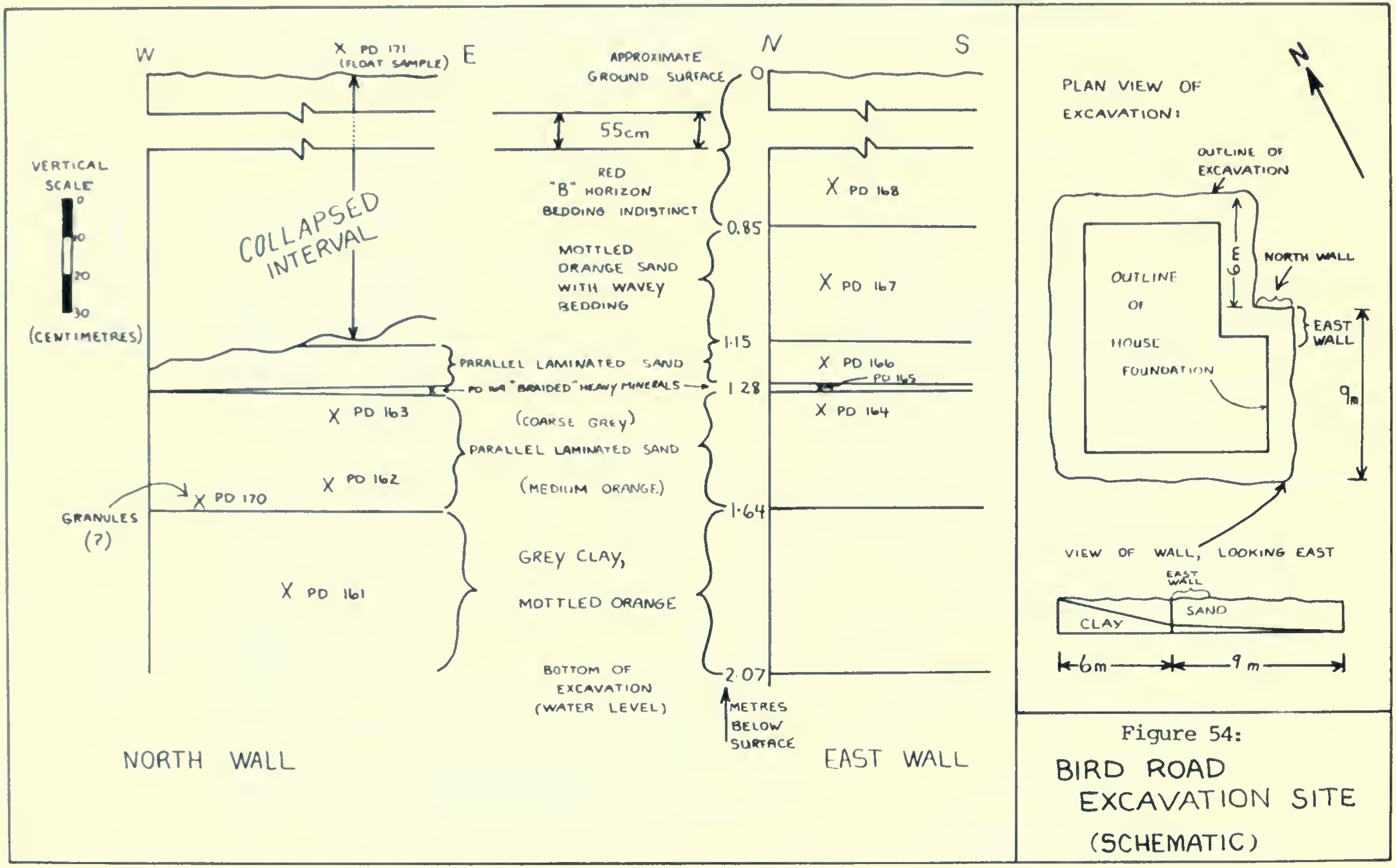


Figure 54:
BIRD ROAD EXCAVATION SITE (SCHEMATIC)

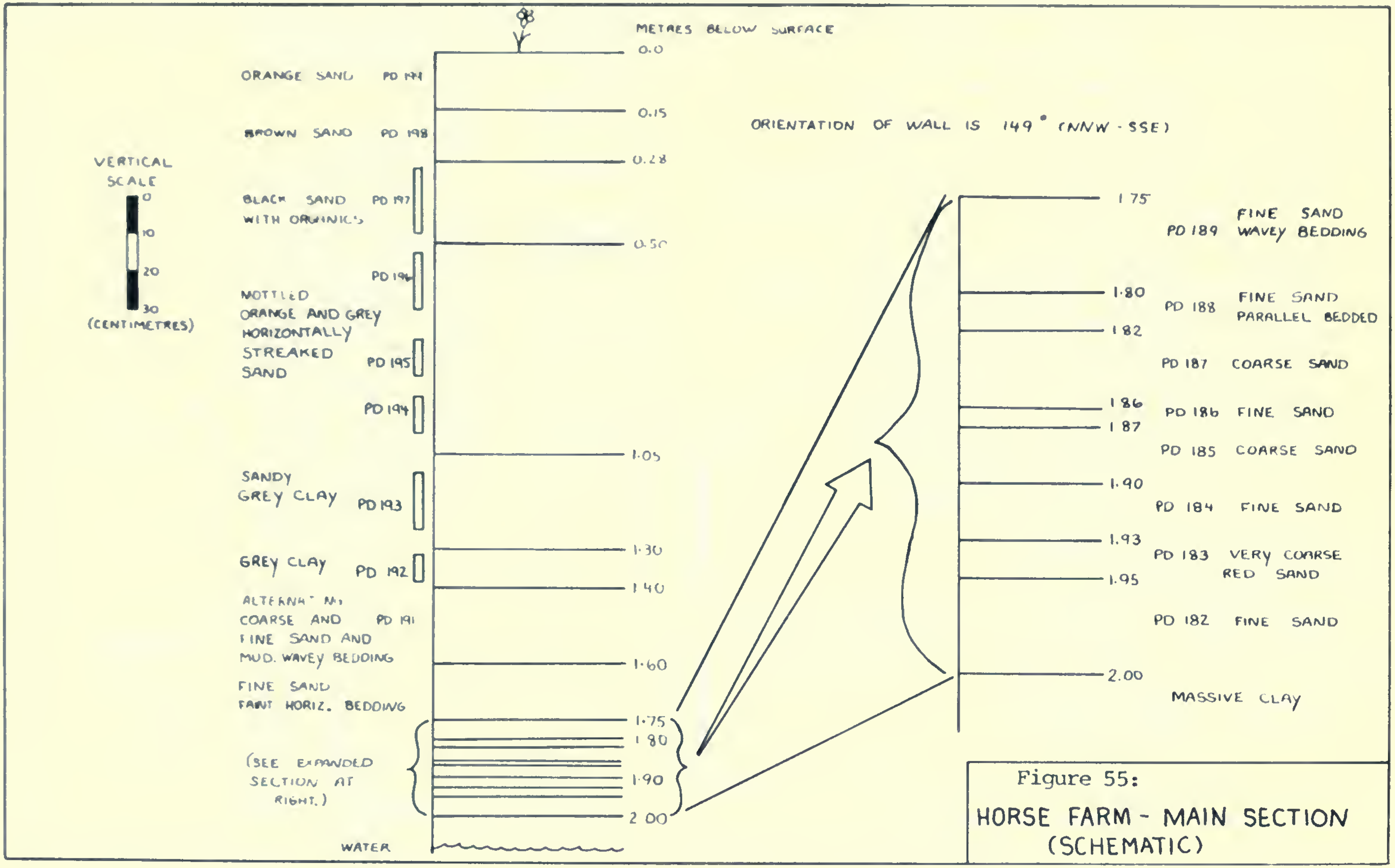


Figure 55:
HORSE FARM - MAIN SECTION (SCHEMATIC)

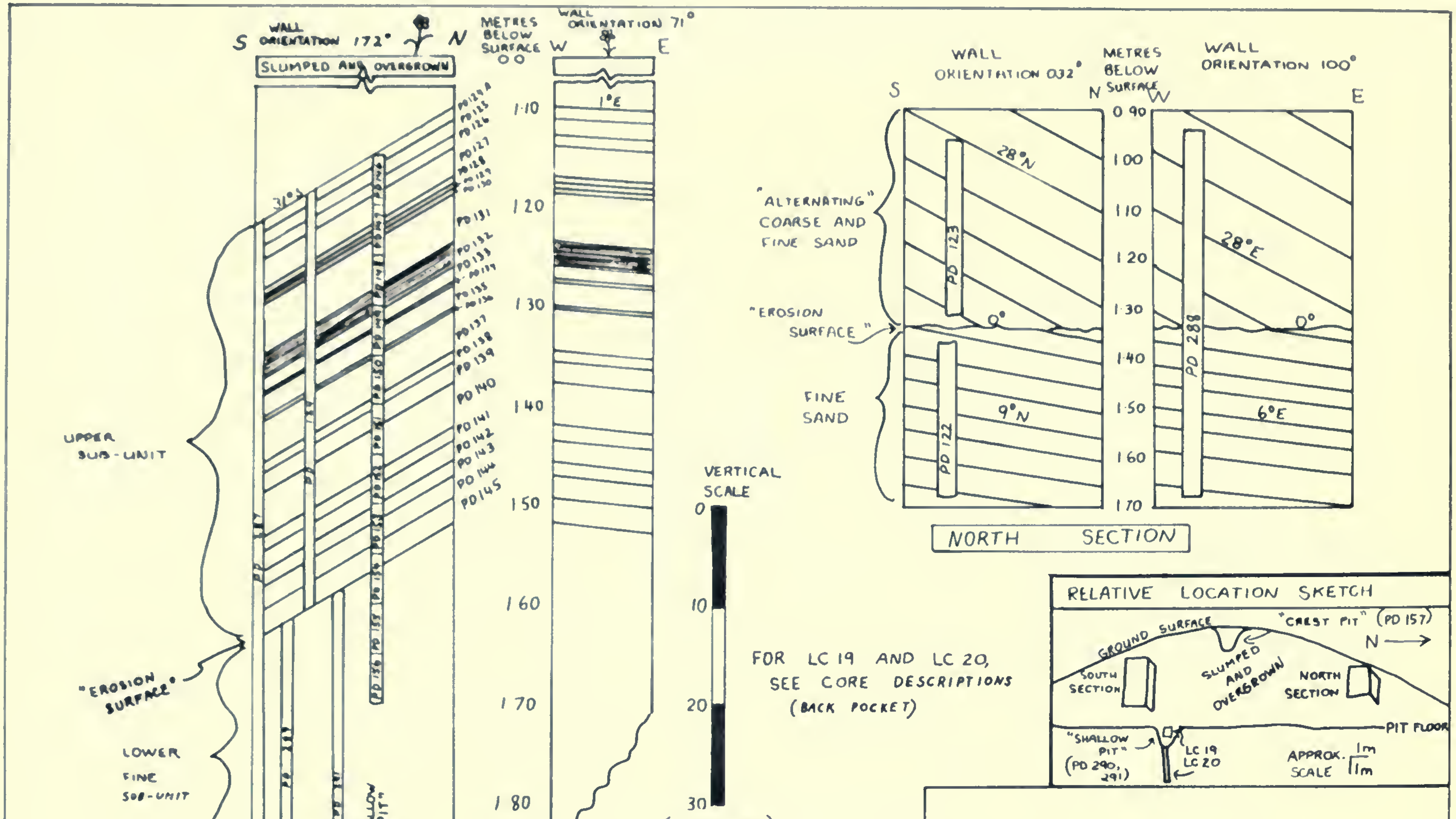


Figure 56:
CEMETERY DUNE SECTIONS (SCHEMATIC)

APPENDIX VII

Computer Output Example

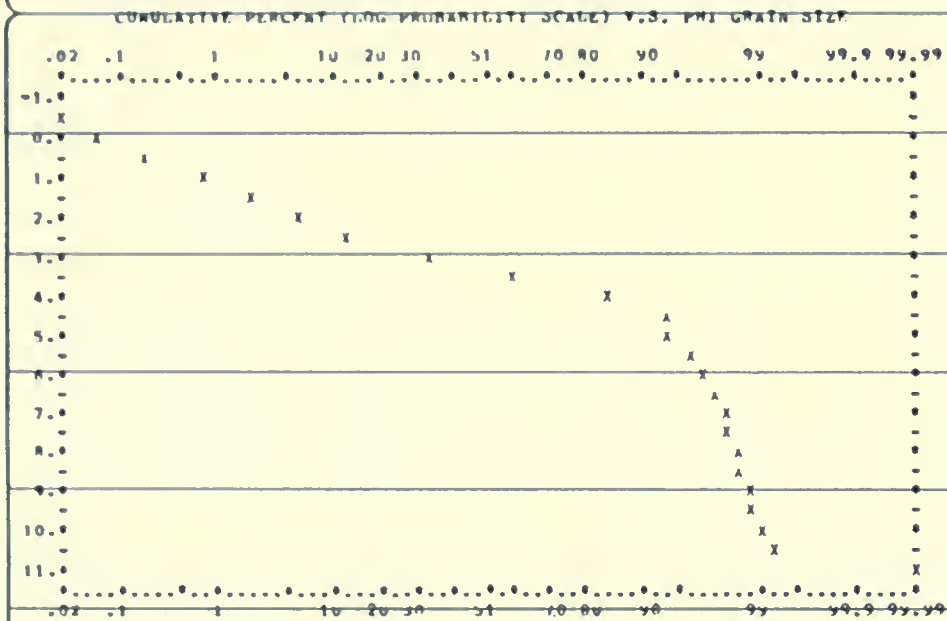
PU 202 21

SIEVE SIZE	PERCENT AGGREGATED	WEIGHT	CUMULATIVE WEIGHT	PERCENT	CUMULATIVE PERCENT	FREQUENCY
-.50	.00	.090	.090	.02	.02	
.00	15.00	.196	.285	.04	.06	-.037
.50	20.00	.773	1.058	.16	.21	.195
1.00	20.00	3.285	4.343	.66	.88	.818
1.50	20.00	7.609	11.952	1.53	2.41	2.195
2.00	4.00	16.585	28.538	3.34	5.75	4.875
2.50	2.00	32.088	60.626	6.47	12.21	9.807
3.00	.00	93.668	154.293	18.87	31.09	25.337
3.50	.00	136.734	291.026	27.55	58.64	46.422
4.00		126.988	418.014	25.59	84.22	53.135
4.50		47.755	465.769	9.62	93.84	35.207
5.00		1.843	467.612	.37	94.21	9.993
5.50		6.756	474.367	1.36	95.58	1.737
6.00		6.295	480.663	1.27	96.84	2.630
6.50		2.764	483.427	.56	97.40	1.825
7.00		1.689	485.115	.34	97.74	.897
7.50		1.228	486.144	.25	97.99	.568
8.00		.921	487.265	.19	98.17	.433
8.50		1.075	488.340	.22	98.39	.402
9.00		.921	489.261	.19	98.58	.402
9.50		.921	490.182	.19	98.76	.371
10.00		1.075	491.257	.22	98.98	.402
10.50		.921	492.179	.19	99.16	.402
11.00		4.146	496.324	.84	100.00	

PETRO-CANADA

```
PU 292                                                21

TOTAL SAMPLE WEIGHT        -    [illegible]G.
SPLIT WEIGHT (SAND+MUD)    -    77.81G.     SPLITTING FACTOR -   6.40


PERCENT SILT AND CLAY
                WET FINES  -       9.63%
                DRY FINES  -        .53%
   TOTAL MUD CALCULATED    -      15.78%
            WASHING LOSS   -       5.63%

            PERCENT LOSS   -       -.00%
PERCENT DRY SIEVE LOSS     -     -10.25%
 PERCENT WET MUD GAIN      -        .00%


TEXTURE %          GRAVEL  -        .00%
                     SAND  -      84.22%
                     SILT  -      13.95%
                     CLAY  -       1.83%

SEDIMENT CLASS     -- SILTY SAND--


MODE(S) -
            3.41   PRINCIPLE MODE
            5.46
            8.25
            9.75
```

PETRO-CANADA



PETRO-CANADA

PD 292 21

*** GRAIN SIZE STATISTICS ***

PHI PERCENTILES

1 -	1.05
5 -	1.92
16 -	2.62
25 -	2.87
50 -	3.34
75 -	3.82
84 -	4.00
95 -	5.29
99 -	.00

--FOLK AND WARD--

MEDIAN -	3.34
MEAN -	3.32
STANDARD DEVIATION -	.86
INCLUSIVE SKEWNESS -	.05
KURTOSIS -	1.46
NORMALIZED KURTOSIS -	.59

--INMAN--

MEDIAN -	3.34
MEAN -	3.31
STANDARD DEVIATION -	.69
SKEWNESS -	-.05

--TRASK--

MEDIAN -	.10
MEAN -	.10
SORTING -	.52
SKEWNESS -	1.00

--MOMENT STATISTICS--

MEAN SIZE -	3.44
STANDARD DEVIATION -	1.26
SKEWNESS -	2.68
KURTOSIS -	15.74

PETRO-CANADA

APPENDIX VIII

Grain Size Analysis Manual Worksheet

COLUMN EXPLANATION:

(1) % AGGREGATES-- from Grain Size Data Sheet.

(2) FRACTION WEIGHT-- from Grain Size Data Sheet. Gravel values are for entire sample, not split weights. (Values in this column assume entire sample has been passed through at least a -1.0 Ø (2 mm) sieve.)

(2A) CALCULATED WEIGHT OF AGGREGATES-- Value in Column (2) minus value in Column (3). Use to calculate total weight of aggregates.

(3) WEIGHT CORRECTED FOR AGGREGATES-- if no aggregates present, use same values as in Column (2).

Correct as follows:

ie: 25% aggregates   4.135 grams fraction weight

wt corrected for aggregates is:

(1-0.25) X 4.135 = 3.094 grams

(4) % READING-- Sedigraph values from Grain Size Data Sheet.

(5) FRACTION %--Compute as follows:

ie: at 5.0 Ø (Sedigraph decimal starting %) minus (decimal % reading)

at 5.5 Ø (decimal % reading at 5.0 Ø) minus (decimal % reading at 5.5 Ø)

example: (assume sedigraph starting % is 100 %.)

	Ø size	% reading	fraction %
	5.0	97	1.00 - 0.97 = 0.03
	5.5	91	0.97 - 0.91 = 0.06
	etc.	etc.	etc.
	"	"	"
	"	"	"
last reading---	12.0	20	0.23 - 0.20 = 0.03
	12.5	0	0.20 - 0 = 0.20

NOTE: even though you may not have read a value for (ie.)12.5, you will still get a "fraction %" value here. (This value is loosely considered to be the "leftovers".)

(6) CORRECTED TO STARTING %-- $\dfrac{\text{Value from Column (5)}}{\text{the decimal starting \%}}$

ie: If sedigraph starting % is exactly 100 %, do not fill in this column. If, for example, the sedigraph starting % is 82 %, then all

sedigraph readings must be corrected as follows:

Ø size	fraction %	corrected starting %
7.5	0.06	0.06 ÷ 0.82 = 0.0732
8.0	0.035	0.035 ÷ 0.82= 0.0427

(7) MUD FRACTION WEIGHT-- multiply value from Column (6) by Total wt. of fines.

(8) SPLITTING FACTOR-- value is "1" for Gravel fractions (since values in the gravel range are whole sample values, <u>not</u> split values.)

For sand and mud fractions, compute as follows:

(Total sample wt adjusted for aggregates) minus (Total gravel wt adjusted for aggregates, if any)

divided by

(Pre-wash weight of split adjusted for aggregates)

NOTE: This value will be identical for all fractions from -0.5 Ø to 12.0 Ø , inclusive. (Also used if there are any values for Ø readings beyond 12.0)

(9) TOTAL FRACTION WEIGHT-- Column (3) (gravels and sands) <u>OR</u> Column (7) (mud)

multiplied by

Value in Column (8).

(10) % WEIGHT OF TOTAL-- values in Column (9) divided by total sample wt (adjusted for aggregates)

multiplied by 100.

(11) CUMMULATIVE %-- value in Column (10) plus sum of all values above it.

ie:

Ø size	% wt of total	cummulative %
-5.0	0.01	0.01
-4.5	0.16	0.17
-4.0	1.25	1.42
-3.5	2.93	4.35
etc.	etc.	etc.
"	"	"
11.5	0.16	99.60
12.0	0.09	99.76
12.5	0.24	100.00 (or very close)

The values in Column (11) are plotted on the probability graph on the reverse side of the Manual Worksheet to obtain a grain size curve. Join the data points on the graph and determine Ø values at the various cummulative %'s listed. Compute Median, Mean, Sorting (also known as Standard Deviation), Skewness and Kurtosis.

This procedure assumes the following:
--<u>TOTAL</u> sample has been weighed.
--<u>TOTAL</u> sample has been passed through the -1.0 Ø (2 mm) seive. This gravel portion that has been retained is manually passed through a stack of coarse seives with a -1.0 Ø seive and pan on the bottom. BEFORE YOU SPLIT THE SAMPLE, any granules that pass completely through the coarse stack must be added to the material to be split.

A scientific calculator is extremely helpful. I have used a TI-57 with very good results.

APPENDIX IX

X-Ray Fluorescence Analysis

X-Fluorescence Standards

The following rock standards were used as references for X-ray fluorescence sample analysis:

Elements Analyzed	Sample Type	Standards 1st Run	2nd Run	3rd Run
Major	all	NIP		
		BCS		
		G-2	G-2	G-2
		BCR-1	BCR-1	BCR-1
		BHVO-1	BHVO-1	BHVO-1
		QLO-1	QLO-1	
		G-H	G-H	
		BBR	BBR	
Trace	all	BHVO-1		
		SGR		
		NIN		
		SCO-1		
		RGM-1		
		GSP-1		

Three different runs were necessary in order to properly "bracket" the sample's chemical ranges. The results listed in this Appendix are those for samples reported to have worked the best using whatever run was deemed suitable, at the technician's discretion. (Pinder, 1984, personal communication.)

NIP	
BCS	
G-2	granite
BCR-1	basalt
BHVO-1	basalt
QLO-1	quartz latite
G-H	?
BBR	?
SGR	
NIN	
SCO-1	shale
RGM-1	rhyolite
GSP-1	granodiorite

Precision

The precision limits of the XRF method for major oxides and trace elements are:

(Wt. %)	(ppm)
$SiO_2 = \pm 1.0$	Ba = $\pm$ 129
$Al_2\ O_3 = \pm 1.0$	Zr = $\pm$ 48
T FeO = $\pm$0.2	Y = $\pm$ 9
MgO = $\pm$ 0.05	Sr = $\pm$ 50
CaO = $\pm$ 0.2	Rb = $\pm$ 18
$Na_2O = \pm 0.3$	Zn = $\pm$ 14
$K_2O = \pm 0.05$	Cu = $\pm$ 9
$TiO_2 = \pm 0.1$	Ni = $\pm$ 11
MnO = $\pm$ 0.05	Cr = unknown
$P_2O_5 = \pm 0.05$	V = unknown

(Bazinet, 1980)

Major Oxides (Wt %)

Sample	SiO_2	Al_2O_3	TFe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	L.O.I.	Total
PD 7A	72.48	11.63	3.05	1.18	2.27	1.72	2.06	0.47	0.08	0.12	0.73	95.79*
PD 7B	70.89	12.10	3.72	1.52	2.11	3.66	2.06	0.47	0.10	0.13	1.29	98.05
PD 7C	72.74	11.66	3.42	1.19	2.31	2.99	2.02	0.52	0.09	0.12	0.61	97.67
PD 16	59.20	9.12	2.05	2.31	13.13	0.00	1.56	0.29	0.06	0.10	10.88	98.71
PD 17	64.36	10.36	2.87	1.71	8.62	2.30	1.72	0.37	0.08	0.11	6.81	99.30
PD 18	71.76	11.45	3.29	1.01	2.80	3.86	1.91	0.44	0.09	0.10	1.55	98.27
PD 28 (F)	39.74	5.93	1.93	8.95	18.63	0.00	1.55	0.25	0.07	0.06	23.34	100.45
PD 28 (C)	25.00	3.78	1.69	12.77	23.95	1.05	1.20	0.19	0.10	0.06	32.14	101.93
PD 82	74.03	11.50	2.21	0.94	2.13	2.84	2.05	0.34	0.06	0.09	0.59	96.79*
PD 158	58.81	4.63	1.30	4.25	13.46	2.88	1.08	0.14	0.06	0.06	14.47	101.15
PD 287	57.63	8.88	2.11	3.15	12.68	2.54	1.68	0.32	0.06	0.08	10.84	99.96
PD 288	57.39	8.12	1.76	2.73	13.34	2.95	1.61	0.27	0.07	0.05	11.39	99.68
PD 292	56.74	8.83	2.47	3.03	13.18	1.79	1.69	0.38	0.07	0.10	11.30	99.58
PD 293	60.00	9.45	2.19	3.17	10.79	2.47	1.82	0.35	0.06	0.12	9.14	99.55
PD 294	58.15	7.75	1.80	2.07	13.74	2.74	1.53	0.26	0.07	0.07	11.49	99.68
PD 295	59.53	8.31	1.91	2.57	12.21	3.33	1.63	0.31	0.07	0.08	10.31	100.27
PD 308	56.95	7.90	2.12	2.57	14.14	2.45	1.45	0.30	0.06	0.08	12.04	100.07
PD 313	56.21	7.91	2.50	3.06	13.66	2.45	1.49	0.38	0.08	0.10	11.88	99.71
PD 314	59.07	7.46	1.14	2.33	14.01	1.98	1.46	0.15	0.04	0.05	12.41	100.11
N-09	57.78	8.16	2.37	2.33	13.20	2.59	1.52	0.36	0.07	0.07	10.98	99.41
N-13	66.01	9.97	4.91	2.63	6.74	1.97	1.32	0.73	0.12	0.09	4.69	99.18
N-29	58.94	8.16	2.08	2.17	12.45	3.49	1.55	0.30	0.08	0.07	10.41	99.68
LC28 S9	75.41	10.50	2.12	0.74	1.45	2.95	1.80	0.19	0.03	0.05	1.82	97.07*
LC28 S20 (F')	54.41	6.38	1.82	3.42	16.06	1.29	1.33	0.26	0.08	0.04	14.51	99.59
LC31 S17	57.37	7.61	1.22	2.83	14.90	0.00	1.50	0.14	0.05	0.05	13.82	99.49
LC32 S13	59.85	8.80	1.23	3.14	11.10	3.47	1.62	0.22	0.05	0.05	10.35	99.88
CDP-1	58.63	8.64	2.96	2.38	12.96	0.59	1.54	0.34	0.13	0.10	11.15	99.42
KW-2	47.72	7.31	3.00	5.90	16.33	0.80	1.31	0.50	0.07	0.11	16.32	99.38

*Sample analysis rejected because major element oxides plus L.O.I. fell outside the range 97.5% to 102.5%

(F) = "Fine" portion of sample, coarser than 4.5 Ø and finer than -1 Ø.
(C) = "Coarser" portion of sample, containing particles from -1.0 Ø to -3 Ø (pebbles coarser than -3 Ø not analyzed by XRF).
(F')= Only portion finer than -1.0 Ø; coarser material not analyzed by XRF.

Trace Elements (ppm)

Sample	Ba	Zr	Y	Sr	Rb	Zn	Cu	Ni	Cr	V
PD 7A	519.8	394.5	21.4	358.9	56.8	54.2	22.7	3.1	22.0	68.9
PD 7B	525.1	360.2	24.0	343.4	61.6	63.4	26.4	6.1	20.4	78.2
PD 7C	532.6	405.0	22.0	357.0	53.7	54.7	22.1	3.7	27.9	69.0
PD 16	342.0	193.1	18.0	345.1	40.1	51.3	23.0	1.8	11.7	29.2
PD 17	403.8	267.4	20.2	334.4	46.2	57.6	23.3	3.5	16.9	46.3
PD 18	488.9	296.1	22.1	343.2	55.5	63.8	28.8	5.5	18.4	65.0
PD 18(Repeat XRF)	500.1	299.6	22.1	344.8	56.6	63.9	26.3	5.9	17.3	63.6
PD 28 (F)	254.8	108.4	17.7	277.3	40.8	58.9	33.3	4.3	11.3	28.6
PD 28 (C)	194.7	90.8	16.1	219.4	32.0	56.8	34.9	2.8	6.4	22.4
PD 82	588.0	238.6	20.9	371.5	60.7	53.1	27.1	2.8	19.6	46.2
PD 158	248.8	87.7	16.2	268.8	32.4	53.7	27.3	0.6	7.8	5.1
PD 287	386.4	184.6	17.9	355.9	38.3	50.9	23.2	0.3	7.9	27.1
PD 288	358.5	167.7	17.7	352.6	39.0	49.2	25.8	0.1	11.4	22.6
PD 292	366.2	279.1	18.9	348.1	38.7	52.2	23.8	2.6	13.8	42.7
PD 293	428.1	256.8	18.8	361.6	46.0	51.8	22.9	1.5	22.5	36.4
PD 294	355.1	163.1	17.5	346.5	39.4	51.0	21.6	1.1	9.8	21.9
PD 295	369.0	196.1	18.0	346.8	39.5	52.1	25.3	0.8	14.7	27.5
PD 308	310.8	167.0	17.4	338.5	35.0	51.6	24.6	0.7	9.6	32.0
PD 313	326.6	207.9	17.7	339.0	36.7	50.1	22.3	0.8	13.4	34.4
PD 314	313.8	98.3	16.9	340.3	34.8	49.7	25.0	0.6	9.8	6.2
N-09	298.8	207.7	18.0	333.1	41.9	53.7	22.1	1.3	17.2	37.4
N-13	305.1	347.2	21.0	310.7	31.8	56.1	23.6	2.8	38.2	99.4
N-29	360.2	144.0	17.7	350.3	36.7	51.1	23.2	2.7	8.0	22.2
LC28 S9	486.4	140.8	18.9	327.7	56.3	63.4	29.5	2.0	21.4	23.7
LC28 S20 (F')	275.5	131.9	16.4	314.4	33.8	55.2	24.5	0.5	10.1	25.1
LC31 S17	293.6	102.4	16.8	317.8	38.5	53.0	30.0	0.4	10.7	14.2
LC32 S13	440.6	168.0	18.3	365.8	39.4	52.8	25.0	0.7	13.5	20.7
CDP-1	243.6	149.0	18.9	311.0	45.4	65.7	31.4	5.3	15.9	52.8
KW-2	266.7	440.1	18.8	303.7	30.0	54.5	23.4	1.1	16.1	56.5
KW-2(Repeat XRF)	257.8	443.6	18.7	305.6	29.2	53.6	24.6	1.4	14.2	60.0

(F) = "Fine" portion of sample, coarser than 4.5 Ø and finer than -1.0 Ø
(C) = "Coarser" portion of sample, containing particles from -1.0 Ø to -3 Ø (pebbles coarser than -3 Ø not analyzed by XRF).
(F') = Only portion finer than -1.0 Ø; coarser material not analyzed by XRF.

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