SEDIMENTOLOGY OF THE CENTRAL REGION OF THE BRAMPTON ESKER: AN EMPIRICAL TEST OF AN ESKER SEDIMENTATION MODEL

BY

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ABSTRACT

Eleven facies types, distinguished on the basis of internal grain size and primary sedimentary structure, were obsereved at the central region of the Brampton esker. These facies were then used to perform an empirical test of H.C. Saunderson's model of eskerine sedimentation for this part of the esker. Primarily, the vertical sequence of facies consisted of: (a) cross-bedded gravel representing the front of a prograding delta; (b) delta-front sands that are poorly sorted and characterized by massive structure and parallel lamination; (c) cross-bedded coarse sand recording the migration of sand waves across the topset; (d) trough-shaped cross-laminae of fine sand indicating current ripple migration on top of the sand waves; (e) draped lamination grading into cross-laminae of fine sand showing stoss-side preservation as the ratio of suspended sediment to bed load decreased; and (f) thick layers of silt and clay deposited in stagnant water conditions brought about by delta abandonment. Cut-and-fill structures were also present, giving evidence of distributary channels traversing the delta.

Saunderson's model adequately explains the origin of sediments in the central region of the esker, but some modifications were made on the basis of new evidence revealed by a recently uncovered exposure.

The sedimentary enviroment was that of a delta which consisted of a topset network of distributary channels prograding into a glaciolacustrine enviroment.

ACKNOWLEDGMENTS

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CHAPTER 1

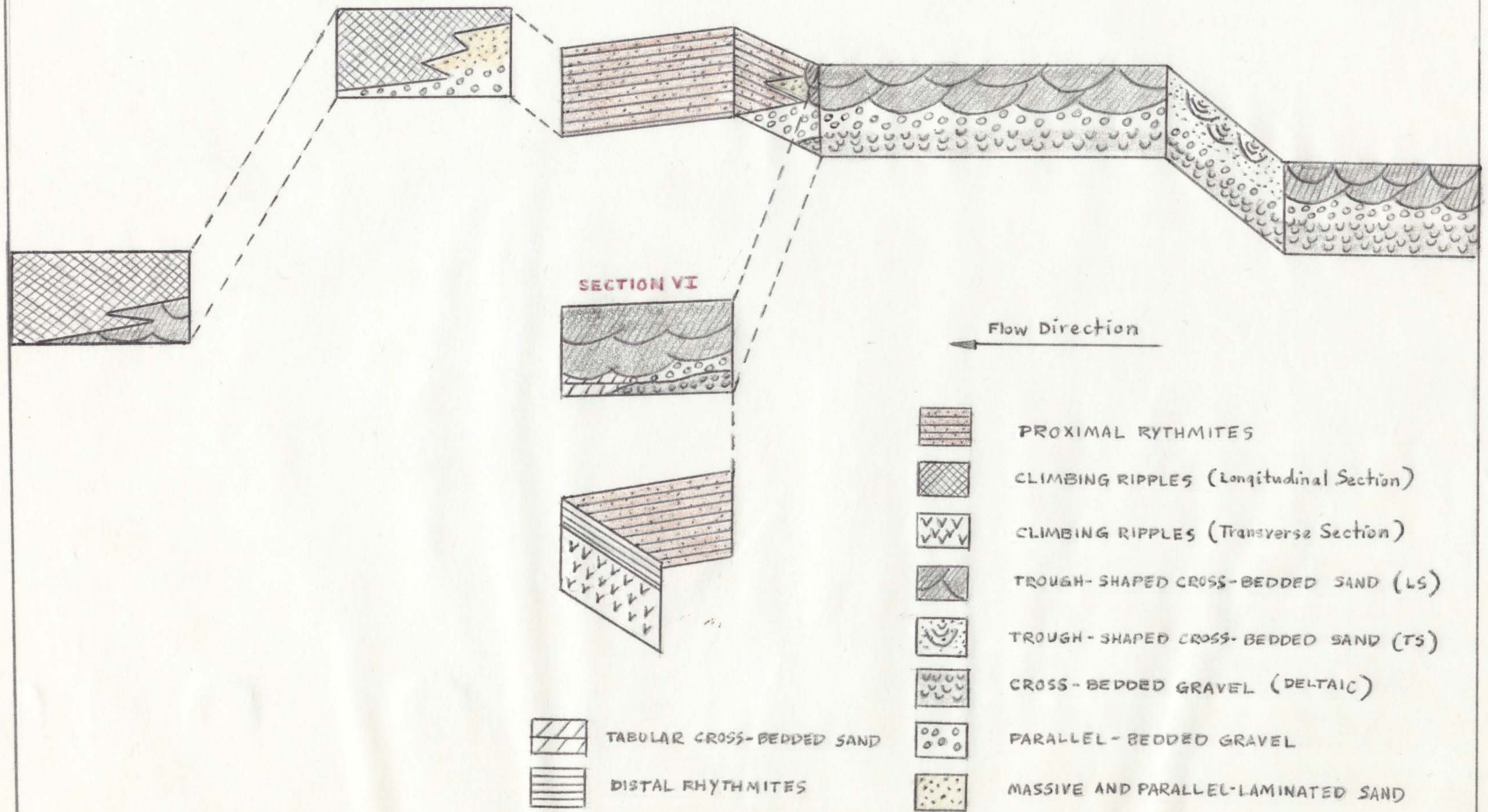
INTRODUCTION

1.1 Introduction

In 1975, H.C. Saunderson presented a paper which had the purpose of describing several hypotheses that attempt to explain the sedimentary enviroments of eskers, and then of testing each of these hypotheses by using sedimentological data obtained from the Brampton esker in southern Ontario. His study involved the examination of the internal grain size and structural properties of the esker and its associated deposits which he grouped into facies to be used in performing an empirical test of the various theories regarding eskerine sedimentation. Saunderson obtained the required data from observations he made in a number of gravel pits distributed randomly throughout the esker. He subsequently measured a number of sections in each pit which were used to diagram the general stratigraphic relationships showing the spatial and temporal facies associations within the esker (Fig.1.1).

This paper is specifically concerned with section VI measured by Saunderson in the Armbro pit. Its purpose is to provide an empirical test of Saunderson's analysis by using sedimentological data from a new exposure within the same pit and to make any necessary modifications to his model on the basis of new insights that may be revealed by

Figure 1.1
Generalized stratigraphic relationships showing spatial and temporal facies associations for the northwestern half of the esker. Paleocurrent direction is approximately from southeast to northwest. After Saunderson, 1975.



the exposure.

1.2 Study Site

The esker is located about 25 km west of Toronto in the northern end of Brampton (Fig.1.2). It is believed to be of late Wisconsinian age and was probably deposited when the Ontario ice lobe was undergoing ablation. During this period the ice was thickest over the Lake Ontario basin (Karrow,1967,69), so that as the glacier receded it did so in a east-southeast direction. The orientation of the longest axis of the esker is approximately normal to the ice front.

Unlike many eskers which are narrow and steep-sided the Brampton esker is a broad, gently sloping deposit of glaciofluvial, glciodeltaic, and glciolacustrine origin (Hewitt and Karrow,1963; Saunderson,1975). It is approximately 7 km long and ranges in width from 0.2 to 0.6 km. The surface morphology of the esker has been obscured to some degree by a layer of unsorted sediment, which Saunderson believes to be till, that covers much of its length. Absolute elevations on the surface of the esker range from 245m to 265m above sea level while the height of the esker above the surrounding terrain ranges from 10m to 20m (Saunderson,1975). In plan, the esker consists of two morphological units. The southeast segment of the esker has a narrow crest which gently slopes towards the flat terrain

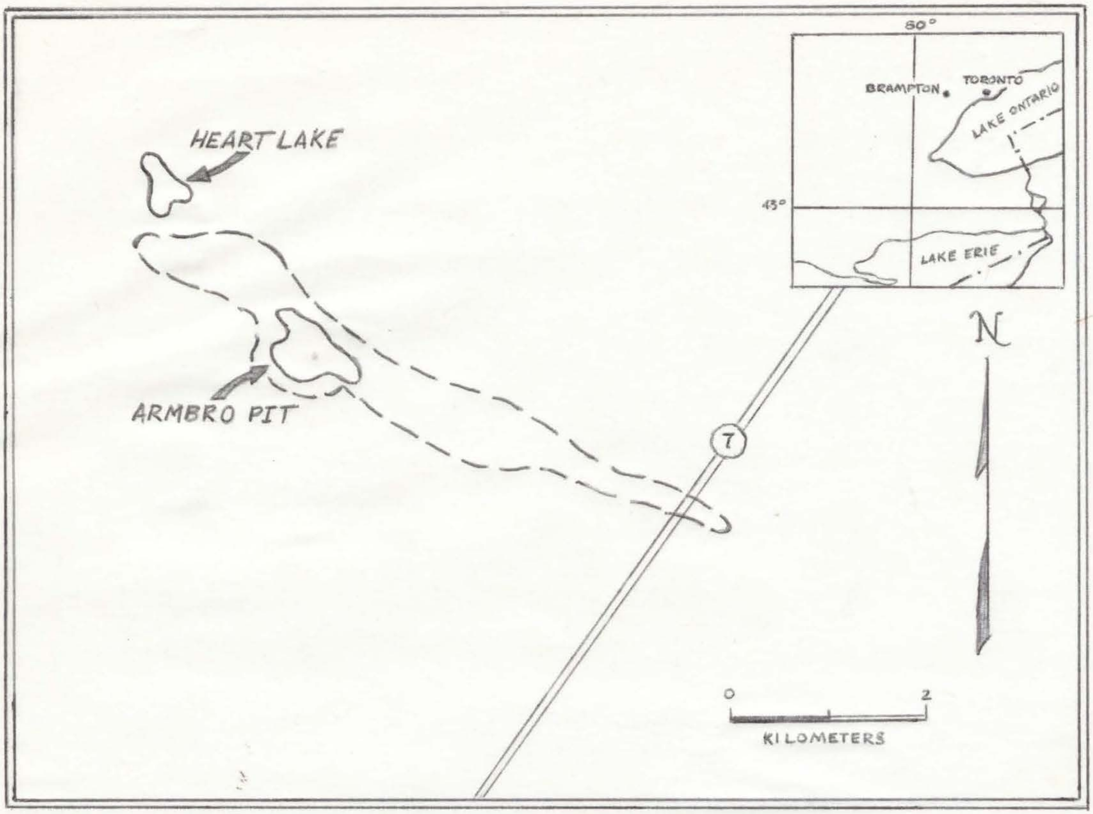


Figure 1.2 Location of field area.

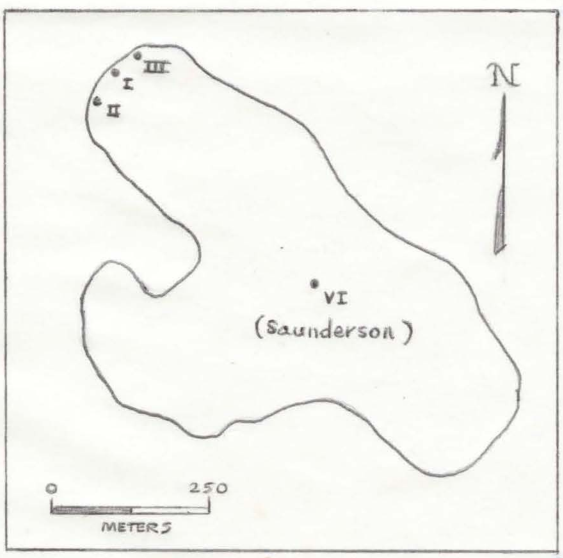


Figure1.2a Armbro pit. The Roman numerals refer to the locations of measured sections.

surrounding the esker. The northwest portion of the esker contrasts its southern counterpart in that it has a much broader crest and a pitted surface, which Saunderson surmised might be the combined result of differential settlement of sediment and the melting of buried ice.

The Armbro pit (Fig.1.2a), in which section VI of Saunderson's study and sections I, II, and III from this study are located, has a central position within the esker. Much of the gravel core of the esker has been all but entirely removed by excavation in this pit, but thick, horizontal beds of massive, poorly sorted sands are abundant dowmstream (northwest) from and around the gravel core. These sands are probably glaciodeltaic and glaciolacustrine proximal rythmites deposited from suspension by very competent streams. Near the core, where sections I, II, and III of this study and section VI of Saunderson's study are situated, the sands exhibit rather complex bedding and evidence of scour-and-fill. Sections I through III are located about half-a-kilometer northwest of section VI which is positioned at the centre of the pit. This site marks the most northwesterly extension of the gravel pit.

1.3 Methodology

The reason for the paper's focus on section VI is threefold. First, several of the pits from which Saunderson measured his sections have been filled and built over, *thereby eliminating any possiblity of cross-examination. Second, of the pits that remain only a couple have been continuously excavated since the time of Saunderson's study, thus allowing for the examination of new exposures which could be used to make inquiries about the rationale of his conclusions. Third, free and easy access could only be obtained for one of these pits - the Armstrong Brothers (Armbro) pit. Furthermore, a relatively new exposure (Fig. 1.3) was in close proximity to section VI in the Armbro pit. It provided a large transverse section through the middle of the esker and revealed much about the origin of the sediments and their environment of deposition. Many distinct layers and sedimentary structures could be observed and, owing to the size of the exposure (approximately 85m wide by 18m high), the lateral extent of the facies and their relationships to each other could be traced. Because of the exposures location with respect to section VI and because of its quality, as determined by the applicability and volume of the information which it could yield. it represented an ideal site from which an empirical test of Saunderson's study could be performed.*

This test involved the collection of grain size and primary sedimentary structure data from the exposure. The data were then grouped into facies of which an interpretation of origin was made. The sedimentological data were

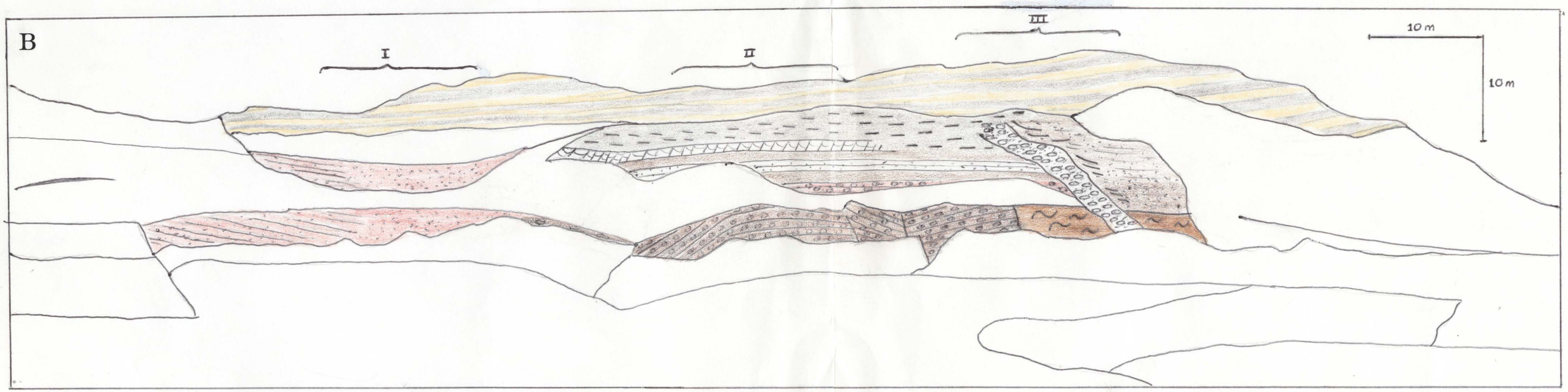


Figure 1.3 A) Picture of exposure where study was undertaken.
B) Line drawing of (A) showing major facies units, that were observed at this site, and their relation to each other. Roman numerals indicate where the sections were measured. For explanation of symbols see figure 1.4.

obtained from the close examination of three relatively wide sections measured at the left flank, middle, and right flank of the exposure. These sections, numbered I, II, and III, respectively (Fig.1.4), provide a representative transverse section of the middle portion of the esker as well as a representative picture of the major sedimentological features of the exposure. These sections were also used to describe the transverse distribution of facies in this portion of the esker.

A detailed knowledge of paleocurrent direction was needed in order to assess the spatial and temporal pattern of sediment dispersion and to integrate separated facies associations into facies associations of the same origin. However, due to time limitations it was not possible to perform a paleocurrent analysis. Therefore, the paleocurrent analysis performed by Saunderson was incorporated into the study to determine paleocurrent direction in those cases where it was difficult to do so from simple observations of dip direction, pebble fabric, and primary sedimentary structure.

In performing a paleocurrent analysis Saunderson calculated the significance of the vector resultant and vector magnitude using those methods described by Curray (1956) for two-dimensional data and by Steinmetz (1962) for three-dimensional data. For a complete explanation of the

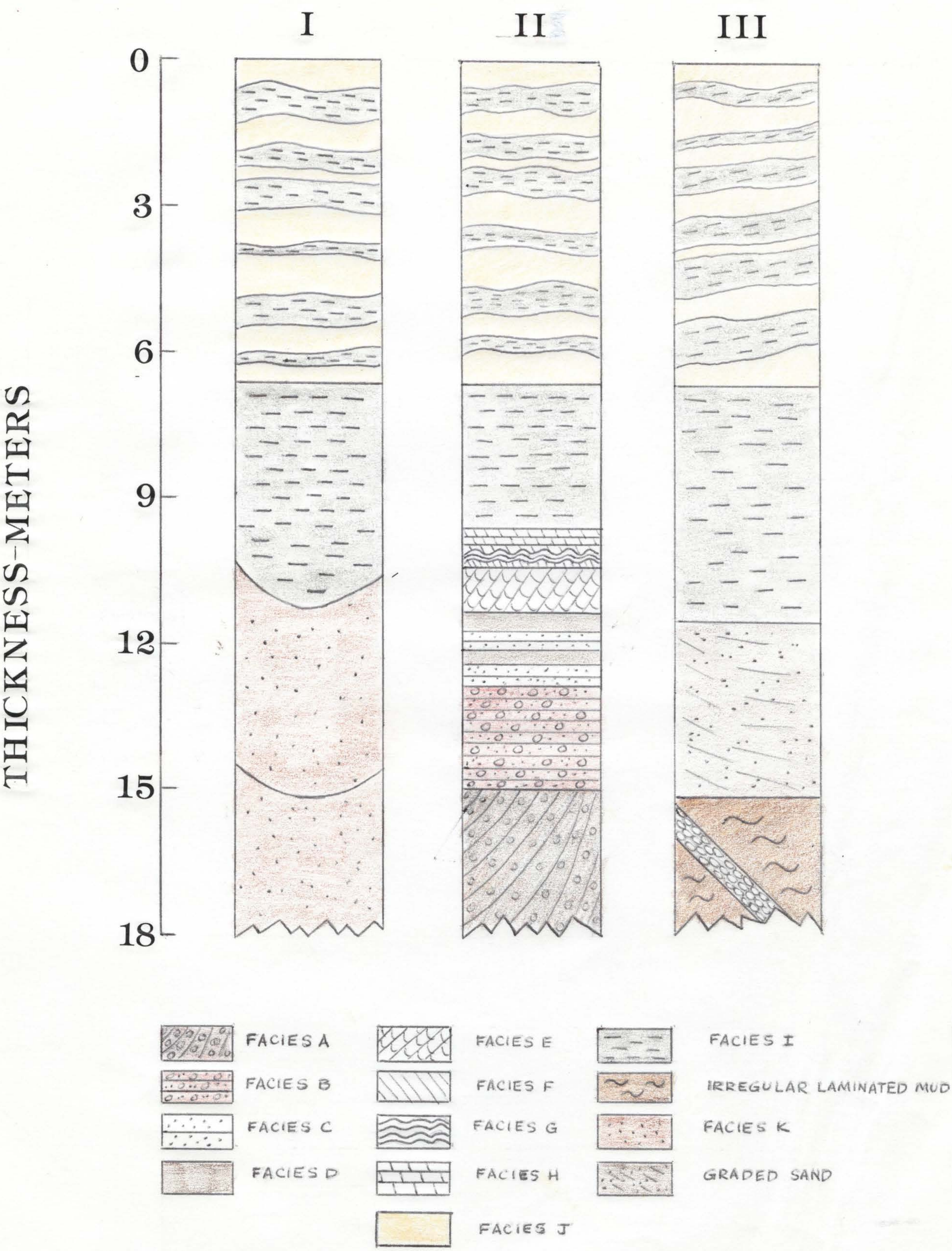


Figure 1.4
Measured sections I-III projected onto a base line parallel to a transverse axis of the central esker region.

field methods used by Saunderson to collect the relevant data one should refer to his paper. Basically, though, the two-dimensional and three-dimensional data used to reconstruct the paleocurrent direction was collected from ripple troughs and cross-bedded sets, respectively. Saunderson employed a statistical method for circular distributions developed by Raup and Meisch (1957) to determine the number of measurements required to determine a significant average dip direction which reflects the paleocurrent direction. He measured samples of 50 observations each where possible which meant that there would be a 95 percent probability that the calculated central tendency of the data would be within ±8 degrees of the actual preferred orientation at each site.

An interpretation of the origin of the facies was then made on the basis of the various facies characteristics such as texture, structure, and morphology as well as on the basis of the interrelationships between different facies. Each of these interpretations were then used together with observations of the larger scale stratigraphic relationships around the sections to provide an overall picture of the processes that were at work when these sediments were deposited. It was then possible to interpret an environment of deposition.

Four hypothetical notions regarding eskerine sedimentation provided the fundamental framework of reference from which an interpretation of the environment of deposition was made. They are: (1) Formation and maintanence of the conduit -- the process by which meltwater was localized in specific channels; (2) Position of esker sediments with respect to the glacier -- wether the esker stream occupied a subglacial, englacial, or supraglacial channel; (3) Nature of the conduit -- wether the esker stream flowed in an open channel (channels without ice roofs) or in a closed channel (a tunnel flowing full); (4) Site of deposition -- wether deposition took place inside the conduit before reaching the glacier terminus, subaqueously in a standing body of water at the ice front where radical changes in flow conditions occur, or subaerially at the glacier terminus (from Banerjee and McDonald, 1975).

The nature of the conduit and the site of deposition can be combined to yield various enviroments of deposition as illustrated in figure 1.5. If deposition occurs within a conduit then the enviroment can either be an open channel or a closed channel. If deposition occurs subaqueously at the terminus then the environment is deltaic no matter the nature of the conduit. Subaerial deposition at the terminus means the environment would be that of an outwash stream. Each of these environments feature a characteristic set of facies, sedimentary structures, and paleocur-

rent patterns. Therefore, by examining the various idiosyncracies of the exposure an environment of deposition may be interpreted.

After determining the facies which are present at the site and after making an interpretation of origin and of environment of deposition, direct comparison can be made with Saunderson's model. Any major discrepancies would suggest that there is a possibility of his model being unsound. In this case the model of this study would be offered as a possible representation of the sedimentology of the central portion of the Brampton esker. Hence, a need for further study would seem to be appropriate. If the models are comparable, this would suggest that Saunderson's model is sufficient. Any minor differences would then be used to modify his model.

CHAPTER 2

A REVIEW OF SAUNDERSON'S STUDY

2.1 The Overall Study

Saunderson began his study by formulating a list of facies based on the distinguishing characteristics of grain size and primary sedimentary structure. Altoghether, he described eighteen facies types, seven of which were found at section VI, which ranged in size from boulder gravel to clay and demonstrated a great variety of primary sedimentary structures. In order to derive some kind of association between facies which could describe their distribution in space and time, Saunderson examined a number of stratigraphic sections, eight in all, throughout different parts of the esker. He also performed a paleocurrent analysis which revealed a predominant paleocurrent direction towards the northwest. However, there was a considerable variation in direction between sites which he believed could be attributed to several hydraulic processes.

He found that the empirical evidence which he had gathered tended to verify the broad characteristics of the De Geer hypothesis, which stated that the coarse esker gravels would be deposited at the exit of a subglacial tunnel where it fed into a standing body of water and that as the competency of flow decreased in the distal direction the sediment would become progressively finer grained, so that

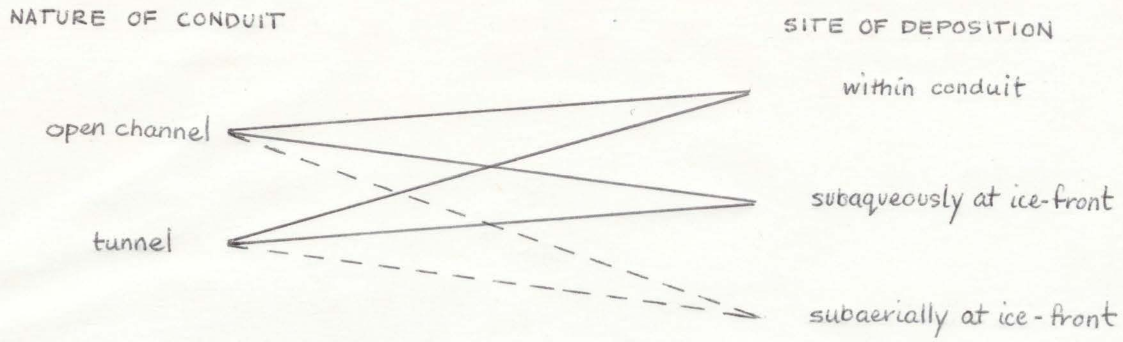


Figure 1.5
Models of esker sedimentation, based on nature of conduit and site of deposition. Dashed lines indicate poorly developed features and improbable recognition as an esker.

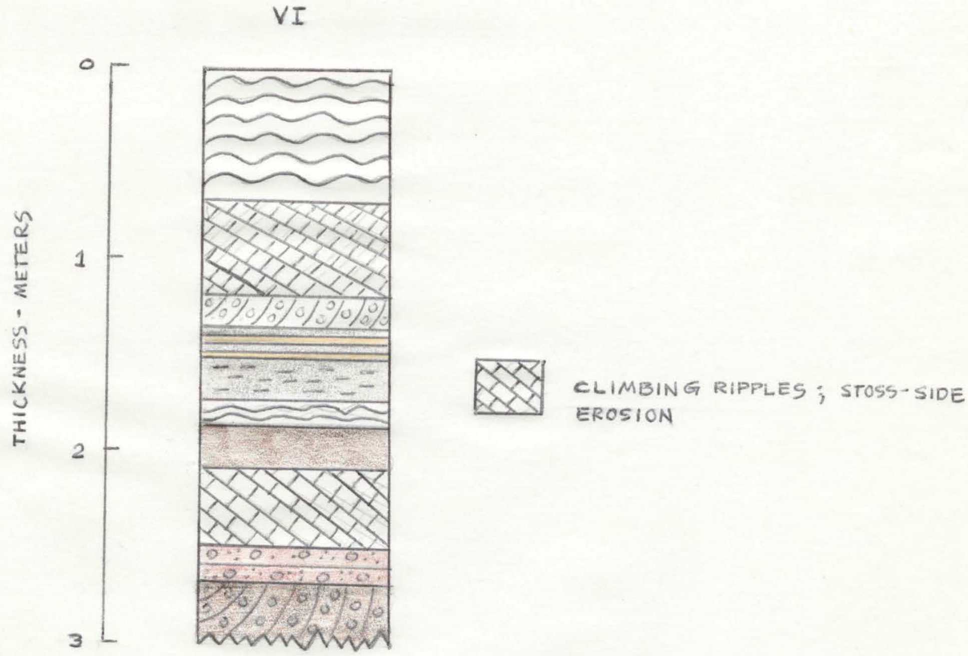


Figure 2.1
Section VI measured by Saunderson. For explanation of symbols see figure 1.4.

there would be a continuous gradation from gravel to clay. He also found that his data revealed a close temporal and spatial association of facies. Therefore, he concluded that DeGeer's hypothesis offered a reasonable model for the prediction of facies relationships in the esker and its associate deposits. Within each time-stratigraphic unit he found that there was a distinctive facies change in the downcurrent direction which consisted of the following gravel to proximal varve to distal varve sequence: (a) cross-bedded san and gravel of glaciofluvial origin; (b) delta front sands that are poorly sorted and characterized by massive structure, graded bedding, cut-and-fill structures, irregular lamination, and parallel lamination deposited in the upper flow regime; (c) cross-laminated cosets of climbing ripple origin; and (d) prodeltaic rhythmites of sand and silt-clay mixtures deposited mostly from suspension. He also stipulated that the structural differences between the esker proper and its associate deposits are probably the result of highly competent streams discharging into a lacustrine environment, the bedding characteristics reflecting changes in relative fall velocity in the down current direction.

2.2 Section VI

Section VI (Fig.2.1) is apprximately 3m thick. It consists of two distinctively fining-upward sequences which *display the same general characteristics. He also observed that as the sediment size decreased vertically, a correspo-nding change in structure also occurred. Each sequence of facies consisted of parallel-bedded gravel at the base, followed by tabular cross-bedded cosets of coarse sand vertically stacked, small-scale cross-laminated cosets of fine sand showing stoss-side erosion, small-scale cross-laminated cosets where stoss-side preservation is evident, sinusoidal lamination in fine silt and clay, and then a thick layer of massive clay. The sequences are separated by a unit of horizontally bedded silt and clay that is app-roximately twenty centimeters thick.*

Saunderson made the following interpretations of origin for each of the above facies types. He believed that the parallel-bedded gravel was deposited in a shallow water environment in the upper flow regime. The tabular cross-bedded cosets of sand were thought to be of subaqueous ag-gradational origin, deposited during intermittent rises in water level. The cross-laminated cosets with stoss-side erosion were interpreted as originating from climbing rip-ples with the sedimentation of suspended load contributing to lee side deposition. The ratio of traction load to suspended load was low, resulting in the stoss-side being eroded. The cross-laminated cosets with stoss-side preser-vation were also accredited to climbing ripples, however, the ratio of suspended load to traction load, at the time when they developed, was high, resulting in the stoss-side being preserved. The sinusoidal laminations in silt were believed to originate from sinusoidal ripples with the sediment entirely being deposited out of suspension. Finally, the massive clay unit and the horizontally bedded silt and clay were thought to be either distal rhythmites or possibly the result of winter deposition in a proximal environment.

The contacts between the different facies are in some cases abrupt and in other instances gradational. The contact between the parallel-bedded gravel and the tabular cross-bedded sand is erosional as is the contact between the latter facies and the cross-laminated facies. The contacts separating the climbing ripple structures are gradational. The tabular sets of cross-beds are, themselves, separated from each other by thin layers of horizontally bedded sands. Among the remaining facies all contacts are erosional.

According to Saunderson the larger scale stratagraphic relationships around section VI indicate that the coarse gravel core was probably that part of a delta which develops at the point of entry of a stream into a lake. He based this interpretation on the following observations: where the gravel is thickest it consists of either parallel *bedding or tabular cross-bedded cosets and that where it decreases in thickness and becomes intertongued with finer grained deposits and bedding becomes hard to recognize. Moreover, he noted that the bedding dipped at 10° and 20° towards the east and west, respectively, away from the gravel core. He surmised that the presence of clays in section VI represented either winter deposition or bottomset deposits that were later covered by topset and foreset deposits as the delta prograded into the lake. Hence, Saunderson reckoned the environment of deposition, for the sediments at section VI, to be deltaic.*

CHAPTER 3

FACIES TYPES

Eleven facies types have been recognized within the study area on the basis of the distinguishing characteristics of grain size and primary sedimentary structure. The facies display a wide range of grain sizes from pebble gravel to clay as well as a variety of sedimentary structures. The main characteristics of each facies types are shown in Table 1.

Facies A: This facies (Fig.3.1) consists of pebble gravel interbedde with very coarse sand which shows low angle cross-bedding, although towards the flanks of the unit it begins to dip by as much as 30°. It represents the coarsest unit found at this section of the esker. The gravel is supported by a very coarse sand matrix which is poorly sorted and has an unstable framework, that is, the coarser clasts do not touch and support each other. The observed maximum thickness of the unit is approximately 3m. It is located stratigraphically near the base of the unit. This unit probably represents the front of a prograding delta. The low angle cross-bedding likely resulted from the deposition of coarse material in shallow water which would prevent the formation of steeply dipping cross-beds. The cross-beds at the flanks of the unit are foresets that were deposited where the water depths became greater (Fig.

Figure 3.1 Low angle cross-bedded gravel core. Notice that in the distance the beds begin to dip steeper; up to 30 .

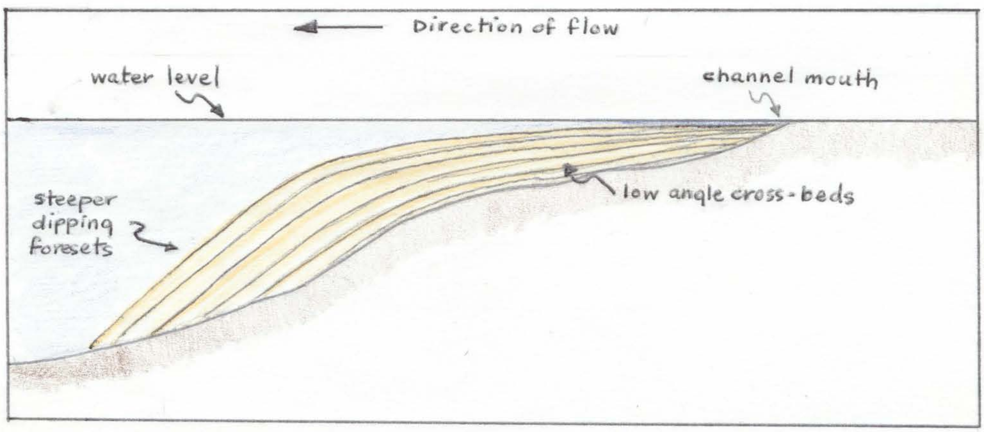


Figure 3.1a Longitudinal section through the gravel core demontrating the variance in the angle at which the beds dip. As the water becomes deeper the foresets dip at greater angles.

3.1a). The grain size of the sediment in this unit indicates that it was deposited in the upper flow regime. Examination of the Hjulstrom diagram (Fig.3.2) shows this to be highly probable. The presence of a poorly sorted matrix suggests that the unit may have been deposited rapidly from a density current.

Facies B: This facies is primarily a very coarse sand with sizes in the coarse sand to cobble gravel range. It demonstrates poor sorting and horizontal stratification. The laminae are in some places distinct, but more commonly are faint and difficult to see. The units thickness is 2.2 m. The horizontal stratification probably developed from deposition on a flat bed in the lower part of the lower flow regime where the sediment was to coarse to permit the development of ripples on the bed (Williams,1967). From figure 3.3 it can be seen that for coarse grain sizes an interpretation as lower flat bed deposits is appropriate. The relative thinness of the sediment layers in this unit are probably the result of the low transport rates that are characrteristic of the lower flat bed phase (Harms et.al., 1975). The combination of horizontal stratification and poorly sorted sediments implies that the sediments were deposited at rapid rates and under changing flow conditions.

Facies C: This facies is essentially made up of poorly sorted medium sand within which there is definite

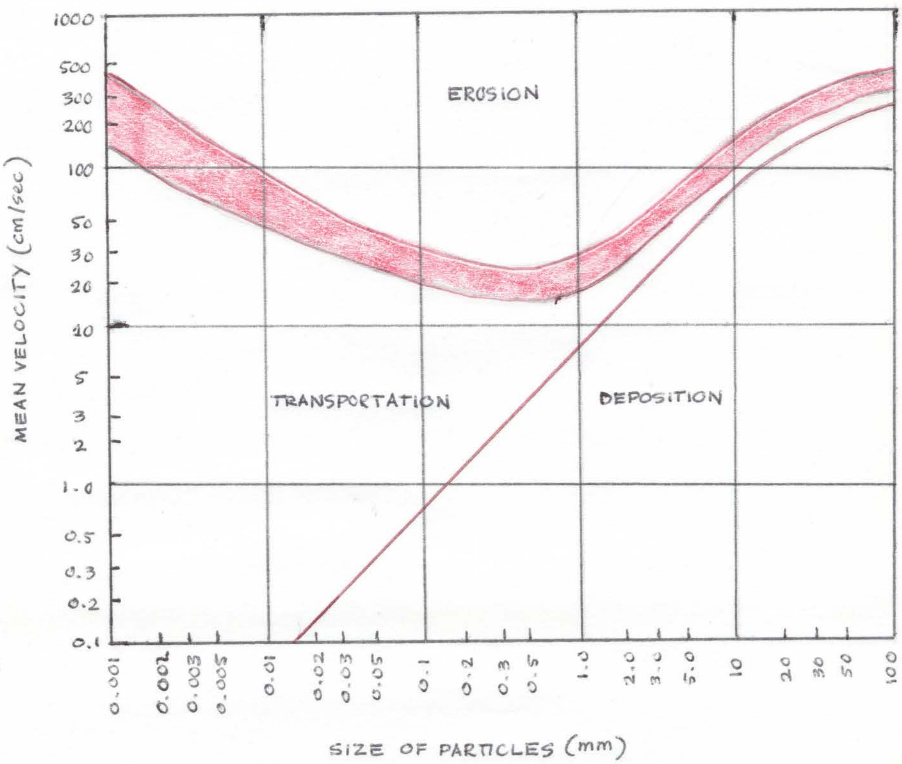


Fig. 3.2 Hjulstrom's diagram. Mean velocity at which uniformly sorted particles of various size are eroded, transported, and deposited.

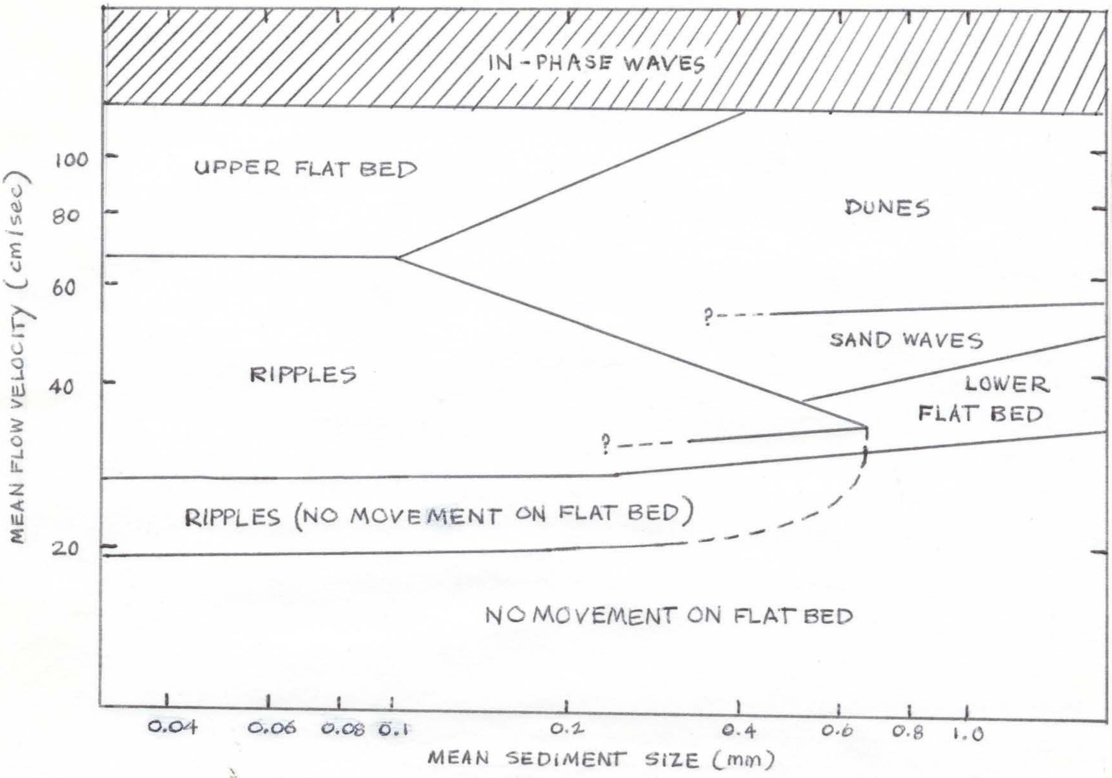


Figure 3.3 Highly schematic size-velocity diagram for a flow depth of 20cm. After Harms et.al., 1975.

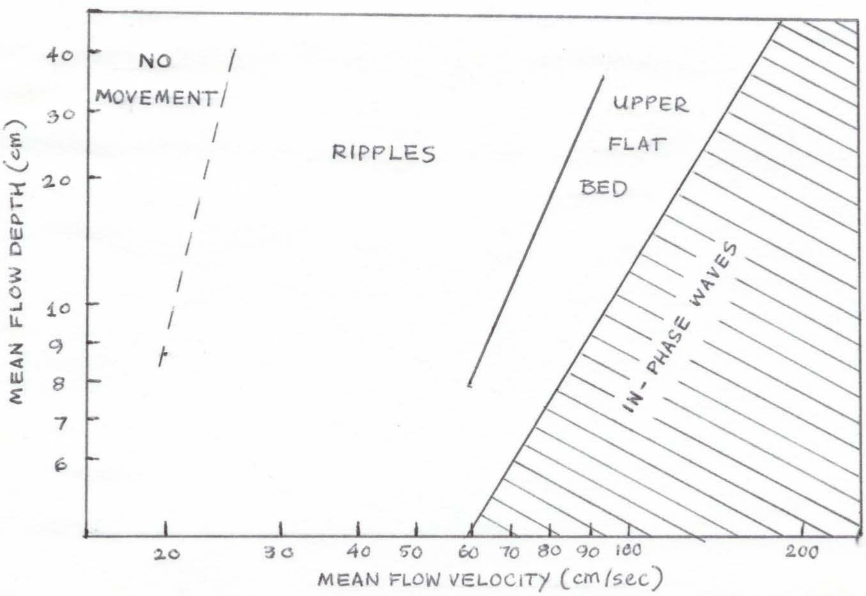


Figure 3.3a Depth velocity diagram for sand size of 0.10mm. After Harms et.al., 1975.

of parallel lamination. This unit probably originated from the rapid deposition of sediment in traction on a plane bed under steady flow conditions in the upper flow regime (Blatt et.al.,1980). This unit is probably a proximal rhythmite.

Facies D: The sediments of facies D consist of poorly sorted, massive beds of gravelly sand. Many of the clasts are of granule size and they probably were preserved as a result of rapid and collective sedimentation following an abrupt reduction in flow competency. This unit is also, in all likelihood, a proximal rhythmite.

Facies C and facies D both occur within the same bed. The bed consists of two C-D sequences (Fig.3.4). The occurence of these facies within the same bed suggests that they were deposited somewhat simultaneously within the same environment. The repetiveness of the sequence indicates that there was a cyclical variation in flow conditions. The cycle could be a reflection of either seasonal fluxes in flow intensity or of changes in flow conditions due to glacial surges. It may even be a reflection of short term variations in weather conditions (Arnborg,1955).

Facies E: This facies is a predominantly coarse sand which displays a cross-bedded structure comprised of large scale (>5cm) cross-bedded sets that are vertically stacked (Fig.3.5). Each of the sets are separated by hori-

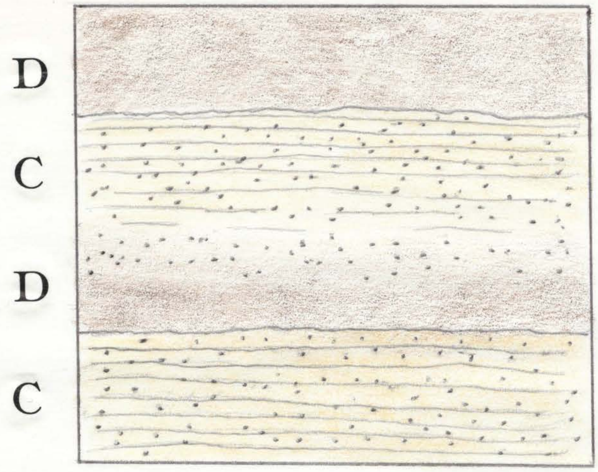


Figure 3.4 Sequence where massive sand (facies D) grades into parallel laminated sand (facies C) in response to changing flow conditions.

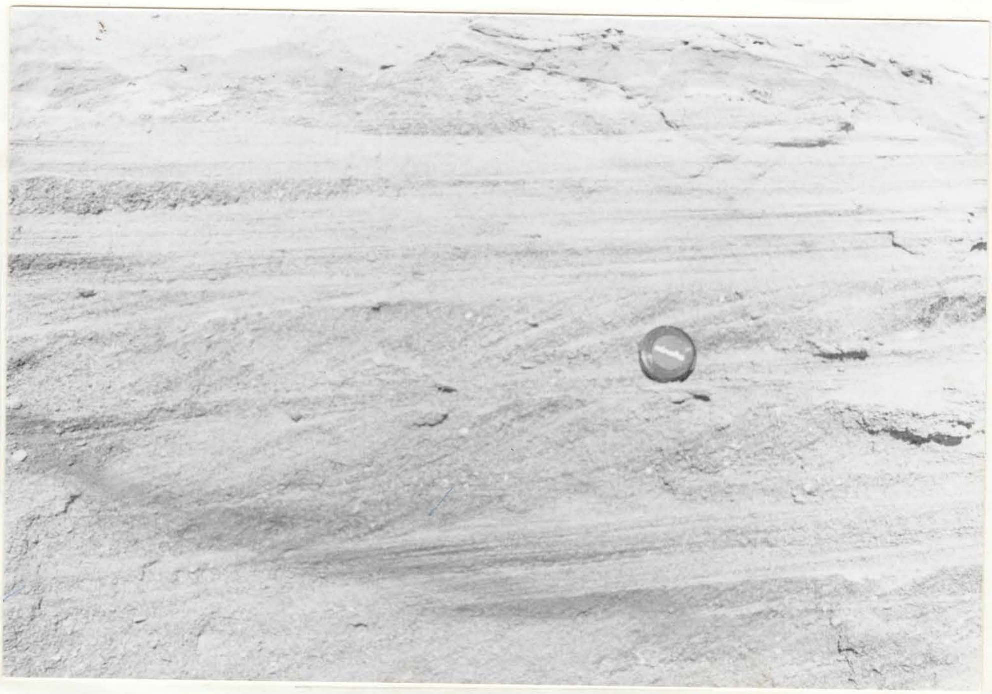


Figure 3.5 Cross-bedded sets of sand separated by diastems. Formed by the migration of sand waves in rising water conditions.

zontal, erosional boundaries that are approximately 6cm thick. Set thickness ranges from 10cm to 30cm. The laminae within the sets become tangential to the boundary in their lower part. This structure was probably deposited by migrating sand waves accompanied by an appreciable aggradation of the bed (Harms et.al.,1975). Intermittent pauses in aggradation would permit erosion to occur thus creating the plane surface which characterizes the upper boundaries of each of the tabular sets. By looking a figure 3.3 plane beds of coarse sand are formed in the lower flow regime. Hence, an interpretation of the cross-beds being of sand wave origin, as opposed to dune origin, appears to be more reasonable, for a large change in flow velocity would have to occur in order for a transition from dunes to plane bed to take place. The transition from sand wave to lower regime plane bed back to sand waves appear to be a result of the flow velocity rising (transition from plane bed to sand waves) and falling (transition from sand waves to plane bed). A transtion would occur when the velocity crossed a threshold of approximately 30cm/sec.

Some of the tabular sets of cross-strata are interrupted by sloping surfaces which separate otherwise apparently conformable sets of laminae. These surfaces most likely are reactivation surfaces which were formed by a cessation in the steady advance of the migrating sand waves.

The interruption probably resulted from a change in flow conditions that may have accompanied a lowering water level (Collinson,1970). After this interruption sand wave migration was resumed when the water level began to rise to the point where a shift back to the conditions appropriate for sand wave development occurred.

Facies F: Facies F is exclusively composed of fine sand with abundant small-scale (>5cm) trough-shaped sets of cross-laminae. These troughs are mostly less than a centimeter thick and a few centimeters wide. This structure was probably formed by current ripples (Allen,1968) developed under low flow strenth conditions. The hydrodynamic range for ripples of fine sand is shown in figures 3.3 and 3.3a. These ripples were distributed on top of the sand waves (Fig.3.6); an association commonly observed in geomorphological studies.

Facies G: This facies consists of superimposed undulating laminae, which at times show slight displacement in one direction, of silt and clay which parallels the underlying bedform (current ripples); hence, giving rise to their symmetrical shape (Fig.3.6). The thickness of the laminae remains essentially unchanged across both symmetrical and asymmetrical surfaces. This structure is believed to be the same as the draped lamination of Gustavson et.al. (1975). The relationship which exists between the laminae

Figure 3.6 Sequence of facies moving from cross-bedded sand to trough-shaped small-scale cross-lamination to draped lamination. Flow strength decreases upwards.

Figure 3.7 Alternating horizontal beds of silt and clay deposited in stagnant water conditions.

and the underlying bedform suggests that deposition occurred from suspension. This interpretation of dominant suspended-load deposition is strengthened by the continuity of the laminae and by their fairly uniform thickness and size composition. Further support for this explantion comes from the work of Allen (1971) who produced similar structures in a flume. The grain size of this unit signifies that the flow velocity at the time of deposition was approximately 0.5cm/sec, as determined from the Hjulstrom diagram (Fig. 3.2).

Facies H: Facies H is composed of medium to fine sand and shows signs of small-scale cross-lamination. This structure was probably formed by climbing ripples (Allen, 1963b and McKee,1965) deposited under low flow strength conditions coupled with an abundant temporarily suspended sediment supply. The presence of stoss-side preservation in the ripple structures implies that the volume of sediment falling out of suspension was greater than the volume of sediment being moved as bed load (Walker,1969). The ratio of suspended load to traction load is therefore considered to be high, but less than the same ratio in facies G. This structure is thought to be the same as the type B ripple-drift cross-lamination described by Jopling and Walker (1968).

Facies I: This facies is simply a massive clay unit.

TABLE 1 - TYPES OF FACIES AND THEIR CHARACTERISTICS

FACIES TYPE	GRAIN SIZE	PRIMARY SEDIMENTARY STRUCTURE	INTERPRETATION
A	PEBBLE GRAVEL	LOW ANGLE CROSS-BEDDING; HIGH ANGLE CROSS-BEDDING TOWARDS THE FLANKS OF UNIT	UPPER REGIME; SHALLOW WATER DELTA FRONT
B	COARSE SAND TO EBBBLE GRAVEL	HORIZONTAL STRATIFICATION	DEPOSITION ON FLAT BED IN LOW REGIME; DEPOSITED AT RAPID RATES
C	MEDIUM SAND	PARALLEL LAMINATION	RAPID DEPOSITION ON FLAT BED; UPPER FLOW REGIME; PROXIMAL RHYTHMITE
D	GRAVELLY SAND	MASSIVE	RAPID AND COLLECTIVE SEDIMENTATION IN RESPONSE TO ABRUPT CHANGE IN FLOW
E	COARSE SAND	LARGE SCALE (>5cm) CROSS-BEDDED SETS; VERTICALLY STACKED; SET THICKNESS 10 - 30 cm	SAND WAVES; RISING WATER LEVEL AND AGGRADATION OF BED
F	FINE SAND	SMALL-SCALE (<5cm) TROUGH-SHAPED CROSS-LAMINATION	CURRENT RIPPLES; LOW FLOW STRENGTH
G	SILT AND CLAY	SUPERIMPOSED UNDULATING LAMINAE; PARALELL	SINUSOIDAL LAMINATION; SUSPENDED LOAD / TRACTION LOAD RATIO LOW
H	MEDIUM TO FINE SAND	SMALL-SCALE CROSS-LAMINATION; STOSS-SIDE PRESERVATION	CLIMBING RIPPLES; SUSPENDED LOAD / TRACTION LOAD RATIO LOW, BUT GREATER THAN IN FACIES G
I	CLAY	MASSIVE	STAGNANT WATER; DEPOSITED WHEN DELTA ABANDONED
J	SILT AND CLAY	ALTERNATING HORIZONTAL BEDS	AS IN I
K	MEDIUM TO FINE SAND	WELL-SORTED; MASSIVE	CHANNEL FILL; DEPOSITED FROM SUSPENSION

Although not strictly structureless, the absence of well defined lamination indicates the absence of a significant traction carpet (Banerjee and McDonald,1975). Hence, this structure probably resulted from the deposition of sediment from suspension. Presumably, the clay was deposited during periods where the velocity and sediment carrying capacity of the flow was low. The clay may have settled slowly to the bottom from surface flow or, as Bradley (1965) proposed it may have settled quickly by means of vertically cascading density currents.

Facies J: Facies J (Fig.3.7) comprises alternating horizontal beds of silt and clay stacked vertically on top of one another. This facies, in all likelihood, is depictive of proximal rhythmites. It reflects a waning flow regime marked by deposition of silt and clay in a shallow water environment.

Facies K: This facies consists of clean well sorted medium and fine sand which is massive (Fig.3.8). Although the unit does show vague parallel lamination in places, it cannot be said to have a structure. The absence of well defined lamination indicates that there was no significant traction load at the time of deposition. The lack of a notable bed load suggests that the water may have been too shallow and too slow to effect any kind of bed load movement, but competent enough to allow for the movement and redeposition of fines.

Figure 3.8 Massive channel fill sands. Towards the channel side the sands begin to show parallel lamination.

Figure 4.1 Photograph of section I located in the center of the exposure.

CHAPTER 4

FACIES RELATIONSHIPS

4.1 Facies Relationships

Three sections were measured at the exposure in order to describe the spatial and temporal distribution of the facies at this site; the location of these sections is shown in figure 1.2a. Figure 1.4 shows the projection of these facies onto a single base line oriented southwest-notheast through the esker. These sections provide a representation of the transverse distribution of facies in the central portion of the esker.

Section II (Fig.4.1) has a central position within the exposure. The lower half of this section is believed to be representative of the proximal part of a delta while the upper half is thought to be proximal deposits associated with delta abandonment. The section consists of cross-bedded gravel, horizontally bedded coarse sand, an alternating sequence of massive gravelly sand and parallel laminated medium sand, vertically stacked sets of cross-bedded sand, current ripple lamination, draped lamination, climbing ripple lamination showing stoss-side preservation, a thick unit of massive clay, and then alternating beds of silt and clay.

The contacts between the facies are both erosional and gradational. Facies B overlies facies A with an erosional contact while facies C overlies facies B with a gradational contact. Within the alternating sequence of sands the contact between facies D and overlying facies C is gradational, but when facies C lies over facies D the contact is erosional. All other contacts, except those between facies F through H, are erosional; even the tabular sets of cross-strata in facies E are separated by thin erosional boundaries or diastems.

The low angle cross-beds at the base of this section are probably the foresets of the proximal part of a delta that were deposited in a shallow lacustrine environment. The steeper cross-beds, which dip towards the east and west away from the gravel core, are probably the foresets of the proximal part of the delta that were deposited slightly further away from the mouth of a meltwater stream in deeper water. This central accumulation of gravel (facies A) is representative of the bed load that was deposited first at the point where a meltwater stream debouched into a glaciolacustrine environment. This locale thought to be analogus to the distributary mouth bar environment associated with a delta.

The occurrence of poorly sorted, horizontally stratified sand and gravel (facies B) on top of the cross-beds of gravel suggests that the water level was rising, so that the sediments were deposited at rapid rates under changing flow conditions in the proximal part of the delta. This

A

B

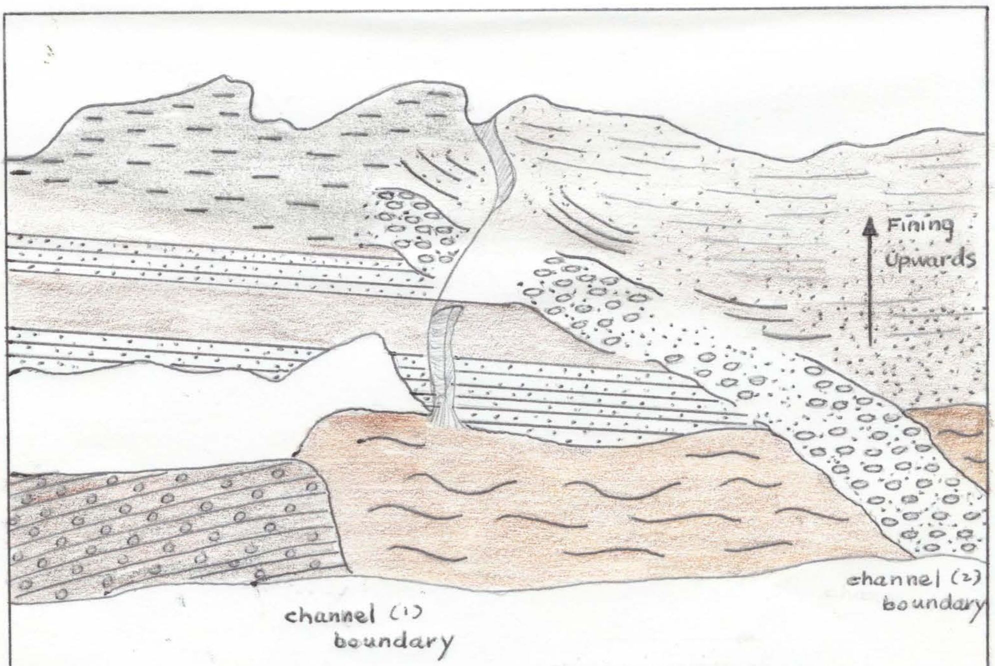


Figure 4.2 Bottom half of section III. (A) Photograph of section (B) Line drawing section of (A) showing channel boundary and sharp contact between cross-bedded gravel and channel fill deposits. Note the fining upward sequence of the channel fill deposits and the angle of the bedding near the boundary. See figure 1.4 for explanation of symbols.

facies then graded into medium sands showing parallel lamination as the flow intensified (facies C). An abrupt reduction in flow competency insued resulting in the collective sedimentation of gravelly sand (facies D). The flow, once again, began to slowly intensify with a lowering of the water level producing a gradual change from massive gravelly sand deposits back to medium sand deposits. This sequence was the repeated. The abrupt changes in flow conditions are probably reactions to rapid increases in the water level associated with the melting of snow and ice in the summer. Hence, it is presumable that facies C and facies D are proximal rhythmites which were deposited on the delta front during the winter, when no terrigenous material was available, and the summer, when abundant detrital material is released, respectively.

The development of tabular sets of cross-bedded coarse sand arranged in vertical stacks (facies E) record the migration of sandwaves across the topset. This structure suggests that the stream profile of the distributary channels was aggrading, possibly in response to a rising water level. The planing of the upper surface of the sand waves could have occurred during intermittent pauses in aggradation and in rising water level (Jopling, 1966b) as the streams attempted to readjust to a new profile of equilibrium. This structure was probably formed as the flow *moved away from the channel mouth over the topset beds. At the same time current ripples (facies F) were moving across the backs of the sand waves.*

The lower halfs of section I (Fig.3.8), positioned to the left of section II, and section III (Fig.4.2), located at the right flank of the exposure, are thought to be representative of channel fill deposits of distributary channels which traversed the upper regions of the delta. The lack of point bar and meander belt deposits indicate that the distributary channels were rather stable and did not have any tendency to migrate laterally (Coleman,1981).

Each section shows evidence of parallel lamination associated with both massive and scour-and-fill structures. At section I parallel laminated sand showing poor size segregation near the sides of the channel dip steeply, at first, towards the center of the channel where the lamination becomes less steep and fades out into a massive unit of sand (facies K). Moving upwards in the channel the sediments become finer grained. At section III the boundary of the channel is marked by a steeply dipping bed of coarse sand and gravel (Fig.4.2). The unit at the base of the channel is irregulararily laminated. A fining upward of the sediments in the channel can also be observed. Bedding within the channel also dips steeply away from the channel side. In addition, the lenticular nature of some of the *parallel laminated units, in both sections, testifies to the occurrence of cut-and-fill.*

The steep bedding at the sides of each channel, which are indicative of scour structures, and the irregular bedding with poor size segregation both suggest that turbulent existed as the channels cut through the deltaic sediments in sync with the progradation of the delta into the lake. The close proximity of granule and cobble sized gravel within the cut-and-fill structures at section III also insinuates that a highly competent stream was discharging into a glaciolacustrine environment. From Hjulstrom's diagram, it can be determined that for the streams to erode the coarse deltaic sediments, flow velocity must have been at least 30cm/sec. Furthermore, the rate of transport from the area of erosion must have been greater than the rate of transport into the area(Blatt et.al.,1980). The scour-and-fill process is associated with a rising water level that probably reflects spring melt and/or the melting of the glacier during the summer.

The channel fill deposits probably occurred as the last stage of the scour-and-fill processes. As the water level fell, with the approach of winter, large volumes of material were deposited in the channel as the river lost its capacity to transport sediment (Church and Gilbert, 1975). Bedforms in the upper part of the channel sections reflect fluctuations in stage.

The thick massive unit of clay (facies I) and the alternating beds of silt and clay (facies J), which are stratigraphically correlated with the top half of each of the three sections, are probably representative of less dynamic facies that were deposited in a lacustrine environment. These facies are thought to be deposits that originated from delta abandonment. Thus, it is probable that they were deposited at relatively slow rates across the entire area of, or at least in the proximal portions of, the former delta (Reading,1978).

4.2 Paleocurrent Direction

Saunderson's analysis revealed that there is a predominant paleocurrent direction toward the northwest, but within this well defined route a considerable variation in flow direction exists. From an examination of the dip, fabric, and structure of the sediments at the study site it was determined that the flow progressed largely towards the west-northwest. However, when the cross-bedded gravel at the base of the exposure was deposited, the flow expanded towards the northwest for a 180° arc from west to east. This variation in flow direction is probably associated with change in the position of the mouth of the parent stream. Inspection of the cross-bedded sands indicates that the sand waves were migrating towards the west-north-

west. Hence, the flow must have been moving in the same direction. The draped lamination structure shows a slight displacement in the same direction indicating the flow was in a west-northwest direction when it was deposited. The climbing ripple structure also suggests that the flow followed the same course. Moreover, the dip of the alternating beds of silt and clay indicate that the flow headed west-northwest. From observation of the channel orientations and the knowledge of the overall trend in flow direction it is believed that the streams which occupied the channels followed a northwest course.

CHAPTER 5

DISCUSSION OF RESULTS

5.1 Environment of Deposition

Figure 5.1 provides a composite of the spatial and temporal sequence of events which led to the arrangement of facies observed within the central region of the Brampton esker.

The central accumulation of gravel at the base of the exposure was deposited as the stream flow in a meltwater channel expanded into a glaciolacustrine environment. The water depth was shallow near the channel mouth causing the development of slight cross-beds, but became deeper with distance away from the channel,thus, allowing for the development of steeper cross-beds. These foreset beds dipped as much as 30° away from the gravel core. The paleocurrent analysis confirms this idea of expanding flow, because the structure, the direction of dip, and the clast fabric all indicate a variability in flow direction. A period of rising water level resulted in the deposition of horizontal beds of sand and gravel. A cyclical variation in water level followed, probably in correlation with seasonal changes in the volume of water entering the lake. This resulted in the deposition of rhythmites proximal to the delta front. An continuous rise in water level with time led to the aggradation of the stream beds accompanied by

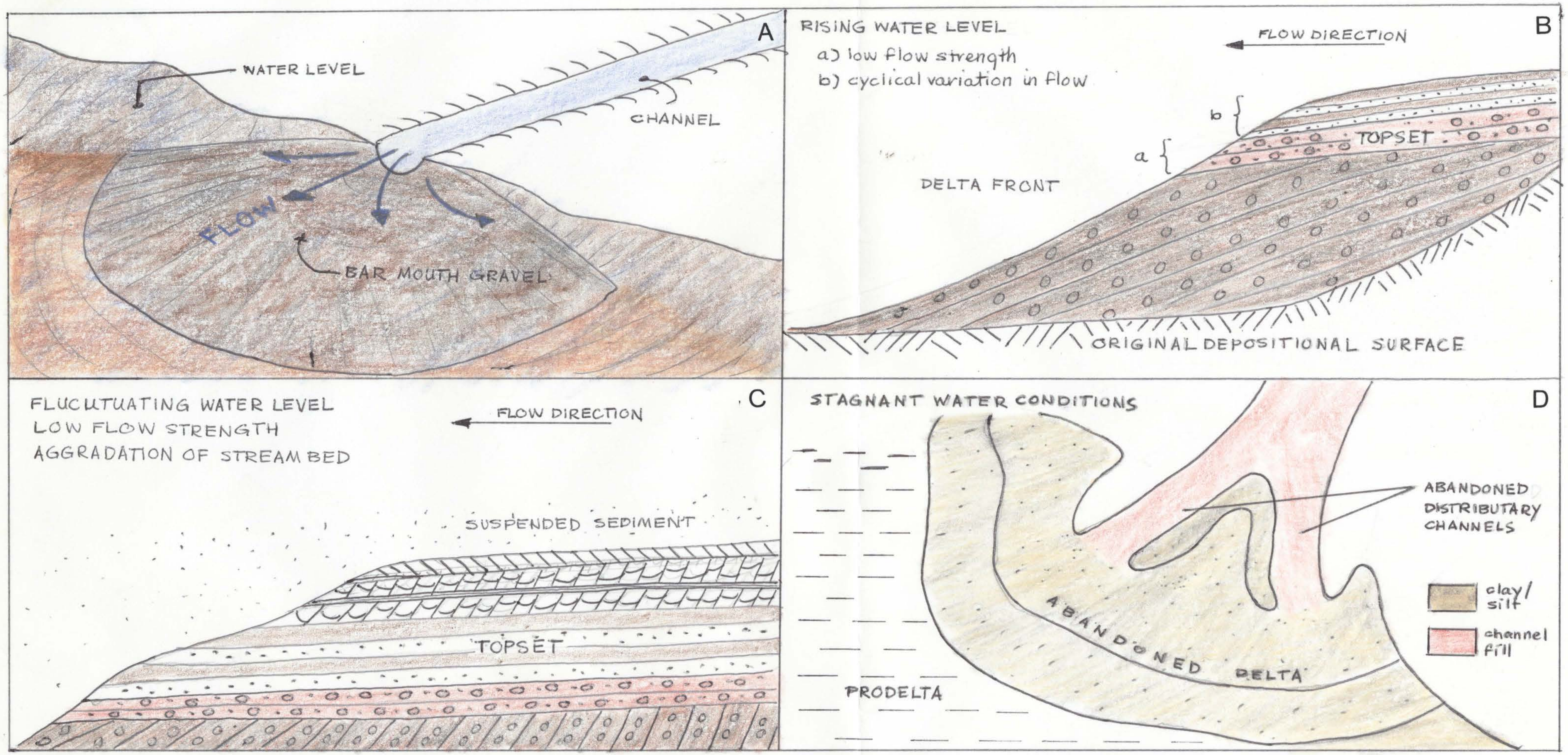


Figure 5.1 Time sequence of depositional events. A) Deposition of gravel core; B) deposition of gravel beds which are parallel; C) sand wav and current ripple migration across topset; and D) abandonment of delta and subsequent deposition of proximal rythmites.

migrating sand waves and current ripples across the topset. Intermittent pauses in the rising water level allowed for the development of diastems between the sets of cross-beds. Even though the water level was rising, the rate of supply of sediment to the lake overcompensated for the rising base level and allowed progradation of the delta to continue. The abundance of suspended sediment and the low flow strength conditions which prevailed at this time were conducive to the development of draped lamination which covered the current ripples. As the bed load movement increased relative to the fall out of grains from suspension, the draped lamination graded into cross-laminae with stoss-side preservation.

While the delta continued to prograde the trunk river divided into distributary channels which cut across the upper delta region each directing a portion of the discharge and transported sediment from the parent river into the glaciolacustrine environment. With continued progradation the distributary channels became overly-extended until a point was reached where the channels were no longer able to maintain their gradients. Thus, channel abandonment insued. Deprived of an active influx of sediment and water the lower portions of the channels became more stagnated and lower current velocities were maintained, the finer grained sediments began to infill the channel proper.

The abandonment of these channels caused the delta to be adandoned. Consequently, the sediment supply to the delta diminished, thereby ending its progradation. The low competency of the lacustrine currents, which became the dominant mode of sediment transport, fostered the gradual deposition of the massive clay unit and the alternating beds of silt and clay over the channel fill sediments and the delta topset. These units were able to achieve their great thickness since the water level was gradually rising probably in connection with the continuous ablation of the glacier.

5.2 Comparison With Saunderson's Model

The empirical evidence tends to verify the general aspects of Saunderson's facies model for the central part of the Brampton esker, but there are discrepancies in interpretation of origin for some of the facies. For instance, in the estimation of this author the presence of clays do not signify either winter deposition or bottom set deposits as Saunderson suggests. Rather, this unit is thought to have been deposited during a long period of stagnant water conditions associated with delta abandonment. Nevertheless the vertical sequence of facies described by Saunderson is basically the same as that which is depicted in this paper. Notable exceptions to this compatibility are (1) the sequence is not repeated as in Saunderson's study and (2) the thickness of the sequence observed in this study is ten times that observed by Saunderson. The first difference may be attributed to the top portion of this exposure being removed by stripping while the difference in thickness can be accounted for by the difference in thickness of three facies in particular. In this study the basal unit of cross-bedded gravel is three times as thick as that in Saunderson's study. This variance is probably the result of more of this unit being exposed by the excavation which has occurred since the time of Saunderson's study. Similarily, the thickness of the massive clay unit and the horizontally bedded silt and clay unit, combined, is nine times that of the same cobination of units measured by Saunderson A possible explanation of this discrepancy is given in figure 5.2. Furthermore, new facies, such as the parallel-bedded sand and gravel and the small-scale troughed-shaped cross-laminae, as well as evidence of distributary channels were revealed at this site, that were undetectable when Saunderson did his work more than ten years ago. His interpretation of the sediments originating from deposition at the edge of a glaciolacustrine environment is believed to be correct, however, as previously stated, the derivation of some of the individual facies suggested by Saunderson is questionable.

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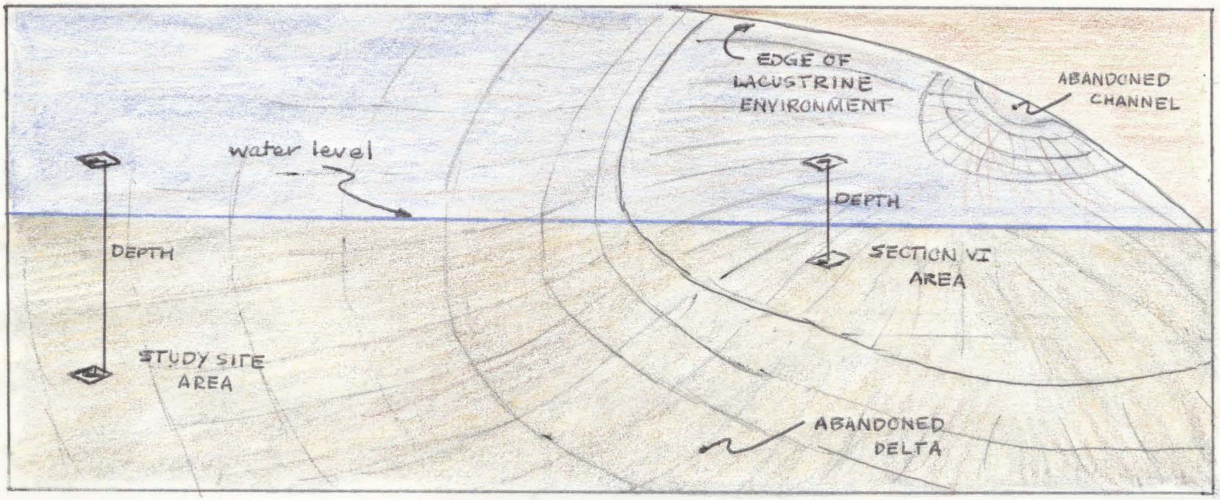

Figure 5.2 At the time the silt and clay was being deposited in the area of the study site, the area around section VI of Saunderson's study was submerged in very shallow water at the edge of a lacustrine environment. Hence, very little sediment was deposited there, but at the study site the water was much deeper allowing for much sediment to be deposited.

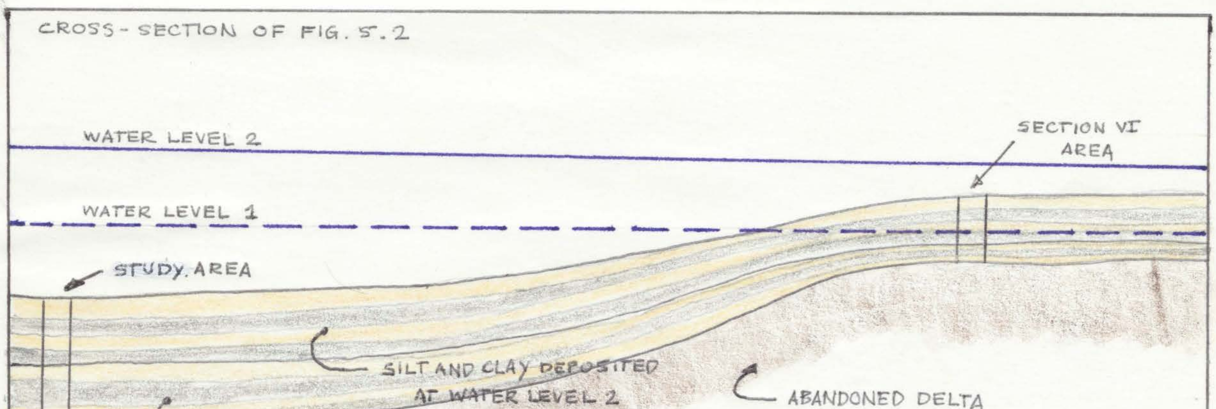

Figure 5.2a As the water level rose it began to encroach on the land. The rising water level accomodated the deposition of more sediment thereby increasing the thickness of the deposits at both sites, but less so near the edge of the lacustrine environment where section VI is located.

CHAPTER 6

CONCLUSIONS

(1) The sediments within the central area of the Brampton esker were probably deposited at the point where the flow from a meltwater stream expanded into a glacio-lacustrine envrionment.

(2) The facies arrangement in this part of the esker typifies a deltaic model of eskerine sedimentation. The cross-bedded gravel marks the front of a prograding delta and the cross-bedded sands and silt on top record sand wave and current ripple migration in the shallower water there.

(3) The topset environment probably consisted of a topset network of rather stable distributary channels. As they continued to prograde with the delta they eventually became over-extended and were no longer able to maintain their gradient. Thus, the channels were abandoned.

(4) The massive clay unit and the alternating beds of silt and clay represent less dynamic facies deposited in a proximal environment under rising water conditions. Sedimentation occurred over a long period of time in association with delta abandonment.

(5) The paleocurrent pattern supports the notion of expanding flow and the interpretation of the facies associations reflecting glaciodeltaic sedimentation.

(6) Saunderson's model offers a reasonable representation of the facies relationships within the central region of the Brampton esker as well as a rational interpretation of their origin. Therefore, the model developed in this paper is submitted as a modification of H.C. Saunderson's model while those interpretations of origin which differ from his are offerred as possible alternatives.

I am curious about ice conditions during the period of esker formation. Does the "till" mantle the entire complex, including your deltaic portion? Is there any ice contact evidence at the more ice-proximal portions of the esker ie faults, recumbent folds, steeply dipping beds & collapse features?

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