THE SEDIMENTOLOGY OF GLACIOFLUVIAL DEPOSITS NEAR UPPER NINE MILE RIVER, NOVA SCOTIA

by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Four sand and gravel pits east of Upper Nine Mile River expose parts of a 25 km long ridge of unconsolidated glaciofluvial sediment. Twenty five(25) stratigraphic sections were measured along fresh exposures in the westernmost pit, owned by Ed Spencer, which is believed to be representative of the entire deposit. Additional observations, comparisons and section measurements were made in three other pits (Babcock, Davis, Nova Scotia Sand and Gravel).

Six sediment types were defined in the field on the basis of clast size and sorting, overall texture, and observed sedimentary structures. These types are: 1) silt and clay; 2) fine sand; 3) coarse sand; 4) gravelly sand; 5)sandy gravel and 6) coarse gravel. Grain size analyses later confirmed the distinctions.

The central core of the Spencer pit is composed of thick, alternating strata of coarse gravels to coarse sands, with thin interbeds of fine sand and silt. The core gravels grade westward to sands and gravelly sands, and all beds thin and fine towards the flanks. This westward and outward gradation likely represents the proximal to distal relationship of an esker bead that was deposited from the mouth of a sub-glacial tunnel.

The Spencer pit is representative of the entire deposit except in two details: 1) Overall, the deposits within the other pits are wider and more continuous. 2) The Babcock pit has more laterally continuous beds in cross-section, and has steeper sided flanks that contain more faults. These differences imply minor differences in the mode of deposition.

The westward paleocurrent directions obtained from the orientation of three-dimensional cross-beds and cross-laminae in the Spencer pit and Nova Scotia Sand and Gravel pit indicate that the sediments were transported towards the west. These measurements and the similarity in composition of the granitic pebbles in the deposits with the Cobequid Highland granites indicate that the depositing ice flow originated to the east or northeast.

ACKNOWLEDGEMENTS

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I am grateful for the co-operation of Ed Spencer, Earl Babcock, Leonard Davis, and the operators of the Nova Scotia Sand and Gravel pit who allowed me to do my field work on their property.

Special thanks are due to Alex Watson for assisting in the drafting of the figures, and to Gayle Regan for typing the manuscript.

Chapter 1. INTRODUCTION

Purpose

The purpose of this thesis is:

1) To study the stratigraphy and sedimentology of a sequence of glaciofluvial deposits.

2) To determine the mode of deposition of these deposits by relating their stratigraphy and sedimentology to the shape and extent of the sequence and to the regional setting of the area.

Location

The glaciofluvial deposits of concern lie in Hants County, Nova Scotia, between latitudes 45^{o} 03' and 45^{o} 05' N and between longitudes 63^{o} 28'W and 63^{o} 45'W. The deposits extend about 25 km as a partially continuous winding ridge, from a point 5 km southwest of Shubenacadie, westward towards Upper Rawdon. This ridge ranges in width from approximately 200 m to one kilometre and reaches a maximum relief of 15 m, generally becoming lower, narrower, less continuous and more beaded towards the west.

The major part of this work is concentrated in one sand and gravel pit approximately 800 m east of the community of Upper Nine Mile River. Additional work was done east of this area in three other pits that expose different segments of the deposit(Fig. 1). Access to the pits is by private unpaved roads off Highway 14.

Previous Work

Previous work on the glacial deposits of the study area was undertaken by Nielsen (1976) and Stea (1982). Both authors briefly mentioned the glaciofluvial sediments but neither studied the stratigraphy and sedimentology of them in any depth. No detailed study of the Hants County glaciofluvial deposits has yet been undertaken.

Economic Importance

The unconsolidated sands and gravels of this glaciofluvial deposit are a valuable economic resource. The sediments have been, and are being extensively excavated in a series of sand and gravel pits. These pits are generally elongate east-west and are of various sizes. The largest is the Nova Scotia Sand and Gravel pit which is approximately five km long and one half to one km wide. The excavated areas tend to be where the deposits are at their maximum width and topographic height.

Topography and Physiography

Most of the glaciofluvial sequence is confined to a gently rolling lowland that ranges in elevation from 30 to 45 m above sea level and generally slopes gently towards the east. The sequence approximately follows the course of the eastward-flowing Upper Nine Mile River, and in many places lies beside, or in contact with, kettle lakes and swamps (Fig. 1). Most of the lowland region is forested; a considerable portion is inhabited and farmed however.

The deposit terminates to the west at the Rawdon Hills, which reach 100 m above sea level.

Bedrock Geology

The bedrock beneath most of the glaciofluvial deposits is relatively soft Carboniferous sedimentary rocks of the Windsor and Horton Groups. These rocks include sandstones, shales, mudstones and carbonates. The Rawdon Hills are underlain by the relatively resistant slates and quartzites of the Meguma Group (Stea and Hemworth, 1980)

Glacial Deposits in the Region and their Relation to Glacial History

The Nova Scotian landscape has been modified in the past 100,000 years by the latest Pleistocene glaciation, known as the Wisconsinan stage (Roland, 1982). Nova Scotia was undoubtedly covered by earlier ice sheets, but the Wisconsinan has largely eradicated the drift of these earlier episodes. Most of the glacial tills remaining today were formed during the erosional and depositional events of the Late Wisconsinan, which lasted from approximately 32,000 to 14,000 years. B.P. (Nielsen, 1976). Deglaciation of Nova Scotia took place around 14,000 years B.P., and by 12,000 years B. P. the mainland was probably mostly deglaciated.

Local ice caps probably remained over the eastern Cobequids and Antigonish Highlands (Prest, 1970) and over the South Mountain (Hickox, 1962) up to, or more recently than, 12,000 years B. P..

Till is the most widespread of all the surfacial materials and covers most of Nova Scotia (Stea (and Hemworth, 1980). Thick till deposits, including drumlins, are most oommon over lowlands and in valleys. The various types of till in Nova Scotia include flow till, melt-out till and lodgement till (Nielsen, 1976). Stea (1982) studied the till stratigraphy of central Nova Scotia, and defined several till units according to the age, texture and type of till.

Other common glacial deposits in Nova Scotia include outwash plains, eskers and kames. These consist of glaciofluvial sands and gravels released as the ice melted. The material was sorted by the seasonal streams and rivers flowing within the glacier, from the glacial front, upon its surface, or beneath it (Roland, 1982).

Eskers are ridges up to 30 m high that were laid down by englacial or subglacial streams as the glacier melted. They consist of poorly-sorted, unconsolidated sands and gravels with abundant water-worn, rounded cobbles and boulders. Eskers deposited in glacial channels within the ice settled to ground level during melting, and the eskers now cross hills and valleys with little change in size. Subglacial channel deposits may fill lower areas and be absent over higher elevations. Hundreds of eskers exist in Nova Scotia, many occurring along pre-existing drainage channels that guided the sub-glacial streams. Most eskers are between one and three kilometres long, although some stretch for much longer distances (Roland, 1982).

Kames consist of stratified fine sand and gravel with locally high proportions of cobbles. Kames are isolated mounds whereas kame terraces are continuous benches along valley sides. Kames formed from material transported into low areas, pools or holes in the ice, or into small ponds around the ice margin. Kame terraces were deposited by meltwater flowing between the ice and the valley side. Both are very common throughout the province, with the terraces being most conspicuous along valleys and at water gaps (Roland, 1982).

Outwash deposits formed when the material released by melting ice was carried away from the glacier, partially sorted and then deposited as the flow velocity decreased. They consist of large areas of relatively uniform, stratified sands and gravels, commonly in low-lying areas, near the mouths of present river valleys, in passes between hills, within larger river valleys, or near former glacial lakes (Roland, 1982).

Apart from the sequence near Upper Nine Mile River, glaciofluvial deposits exist in Hants County west of the Rawdon Hills in the valleys of rivers which flow westward towards the Minas Basin (Stea and Hemworth, 1980). Stea (1982) suggested that many east-west trending eskers and ice-contact features in Hants County were produced by a late westerly ice flow over the region approximately 12,000 years before present. This would imply that they were deposited after the main period of till deposition that lasted until 14,000 years ago.

The glaciofluvial sediments were the last Pleistocene glacial deposits in the Upper Nine Mile River area. They overlie sequences of older Pleistocene tills that cover the entire lowland area (Stea, personal communication, 1983). No evidence for any till deposition on top of the glaciofluvial sequence was found by the author.

Chapter 2. METHODS

Field Work

A segment of the deposit was selected for detailed mapping and data collection. This segment was believed to be representative of the entire deposit, and additional observations were made at other locations to confirm this assumption.

The pit owned by Ed Spencer, located near the community of Upper Nine Mile River, was selected for detailed work because:

1) Abundant fresh excavations provided good exposure.

2) The relatively small size of the pit (approximately 700 m by 200 m) and the small scale of the operation allowed quick and safe mapping.

3) The pit was easily accessible and the owner was helpful and cooperative.

During September and October of 1982, twenty-five detailed stratigraphic sections were measured at fresh exposures in the Spencer pit, and the section locations were accurately recorded by a plane table survey. Recorded for each major sedimentary strata in each section was : clast size, degree of sorting, overall texture and colour of the sediments, degree of consolidation, nature of any sedimentary structures and nature of the contacts between units. Samples of the major units were taken at six section locations for grain size and compositional analyses.

Paleocurrent directions were measured from three-dimensional cross-beds and cross-laminae at 14 locations in the Spencer pit, and later at five locations in the Nova Scotia Sand and Gravel Pit.

During October of 1982, similar observations were made in two other pits, owned respectively by Earl Babcock and Leonard Davis, and located to the east of the Spencer pit. The Nova Scotia Sand and Gravel Pit, located at the eastern end of the deposit, was visited during February of 1983. The general stratigraphy and sedimentology of the deposits at these locations were observed and some sections were measured in the Babcock and Davis pits.

Laboratory Work

Grain size analyses of samples from the major stratigraphic units of six representative sections were conducted by dry sieving following the methods out-lined by Piper (1977, p. 40-52). Divisions were made at $\frac{1}{2}$-phi intervals from +4 phi to -1 phi, and at 1-phi intervals from -1 to -5 phi.

The relative proportions of the clast types in the pebble sized fraction (4-64 mm) was determined to provide a rough idea of clast origins. Samples were taken from the Spencer pit and the Nova Scotia Sand and Gravel pit.

Topographic maps and aerial photos were studied to determine the extent of the deposits and the gravel pits. Much of the information displayed on the included map is drawn from these sources.

Chapter 3. SEDIMENT DESCRIPTION

Sediment Types

Introduction

Six sediment types were originally defined in the Spencer pit on the basis of clast size, clast sorting, overall texture and sedimentary structures. The sediment types are, in order of increasing grain size:

1. silt and mud
2. fine sand
3. coarse sand
4. gravelly sand
5. sandy gravel
6. coarse gravel

Clast size classifications were made according to Wentworth's outline (Table 1).

Grain size was analysed for representative samples from each of the above sediment types except silt and clay, the particles of which were too fine-grained for normal sieving. Each type has a distinctive range of gravel: sand: silt and clay ratios (Fig. 2), and regular patterns of cumulative grain size frequencies (Figs. 3-7). Grain size median and mean, degree of sorting and skewness of each sample are shown in Table 2, with the averages for each sediment type.

Silt and Clay

These sediments are reddish-brown, and, although unconsolidated, are more cohesive than the other sediment types. Stratigraphic units are commonly lens-shaped, finely laminated and, in many cases, contain fine sand bands or lenses.

Wentworth (1922)
after Udden (1898)

		Phi	m.m.
BOULDER			
		-8	256
COBBLE		-7	128
		-6	64
		-5	32
PEBBLE		-4	16
		-3	8
		-2	4
GRANULE			
		-1	2
SAND	Very Coarse		
		0	1
SAND	Coarse		
		+1	$\frac{1}{2}$
SAND	Medium		
		+2	$\frac{1}{4}$
SAND	Fine		
		+3	$\frac{1}{8}$
SAND	Very Fine		
		+4	$\frac{1}{16}$
SILT	Coarse		
		+5	$\frac{1}{32}$
SILT	Medium		
		+6	$\frac{1}{64}$
SILT	Fine		
		+7	$\frac{1}{128}$
SILT	Very Fine		
		+8	$\frac{1}{256}$
CLAY	Coarse		
		+9	
CLAY	Medium		
		+10	$\frac{1}{1024}$
CLAY	Fine		
		+11	
CLAY	Very Fine		
		+12	$\frac{1}{4096}$
COLLOID ↓			

Table 1. Classificaton of sediments according to grain size. From Piper (1977), based on Wentworth (1922).

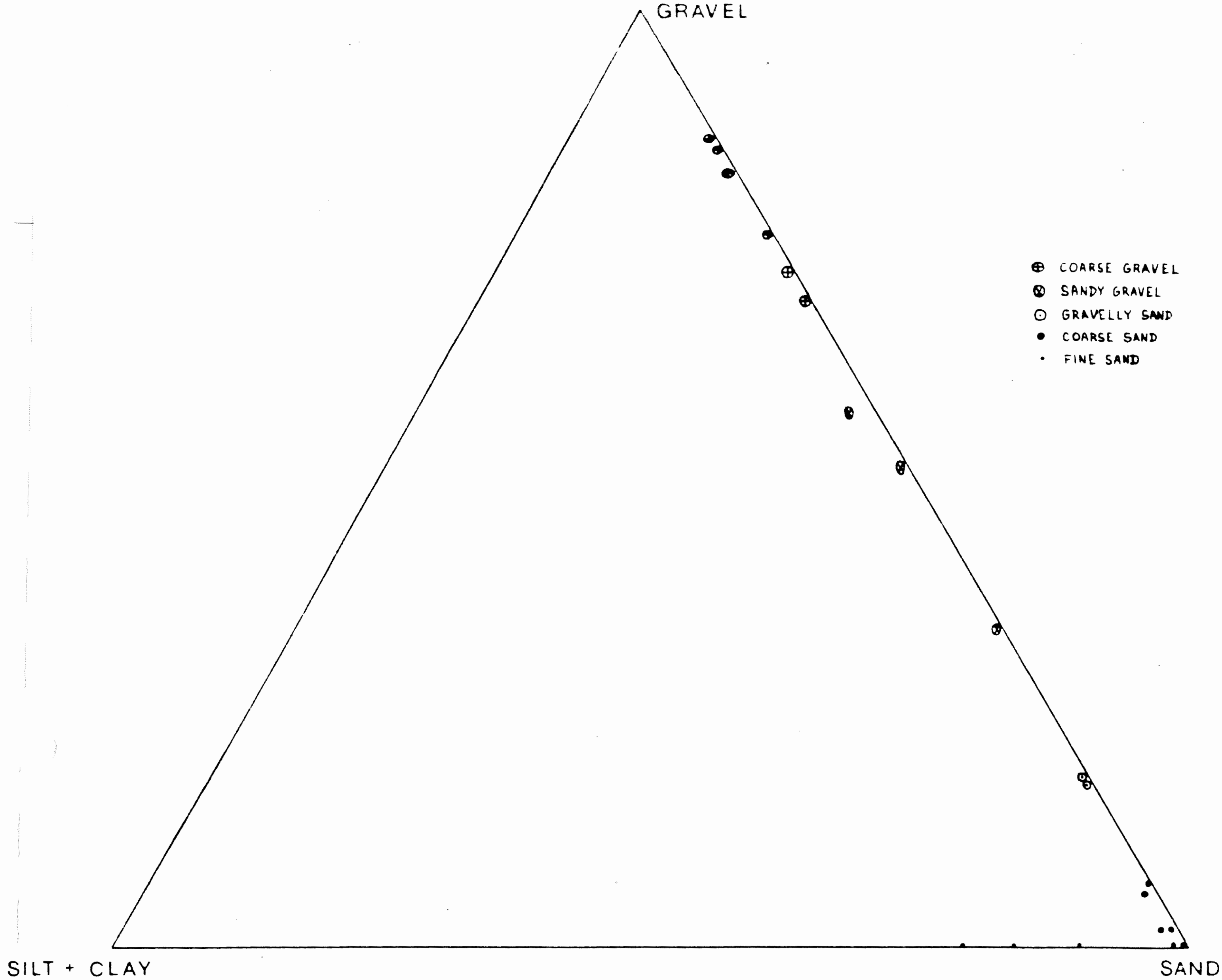


Figure 2. Proportions of gravel, sand, and silt and clay in samples of five of the six sediment types.

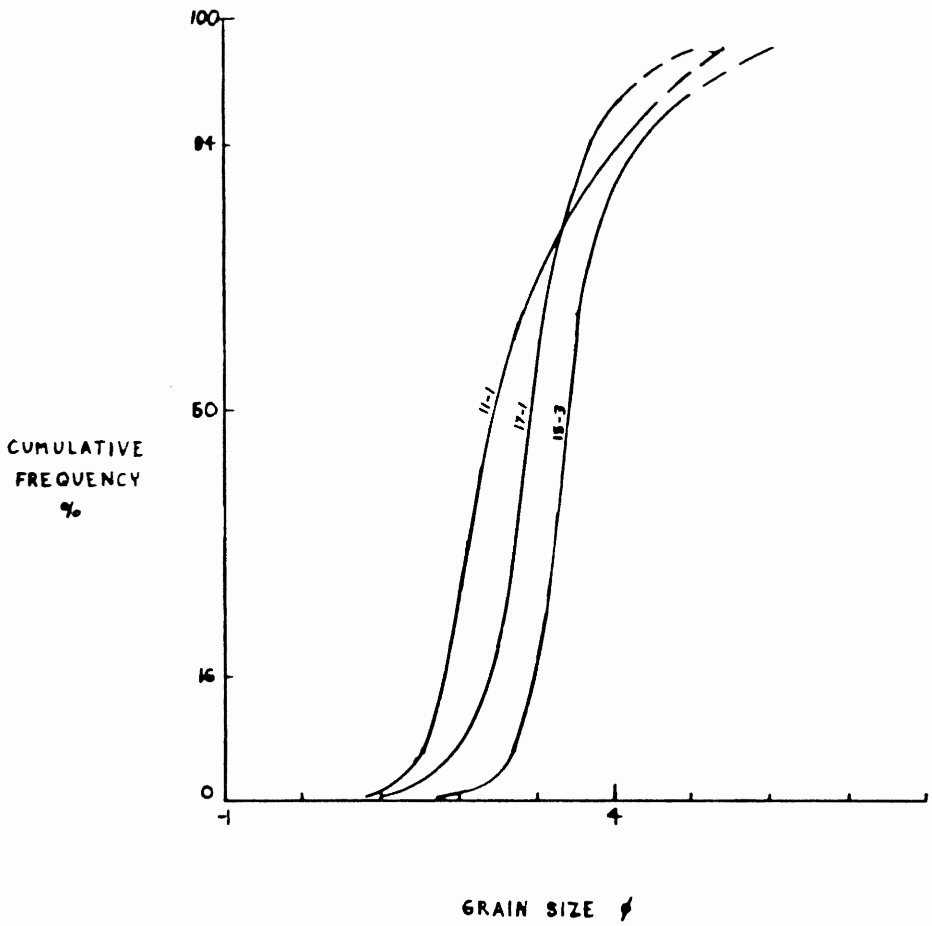


Figure 3. Cumulative frequency grain size distributions of five fine sand samples.

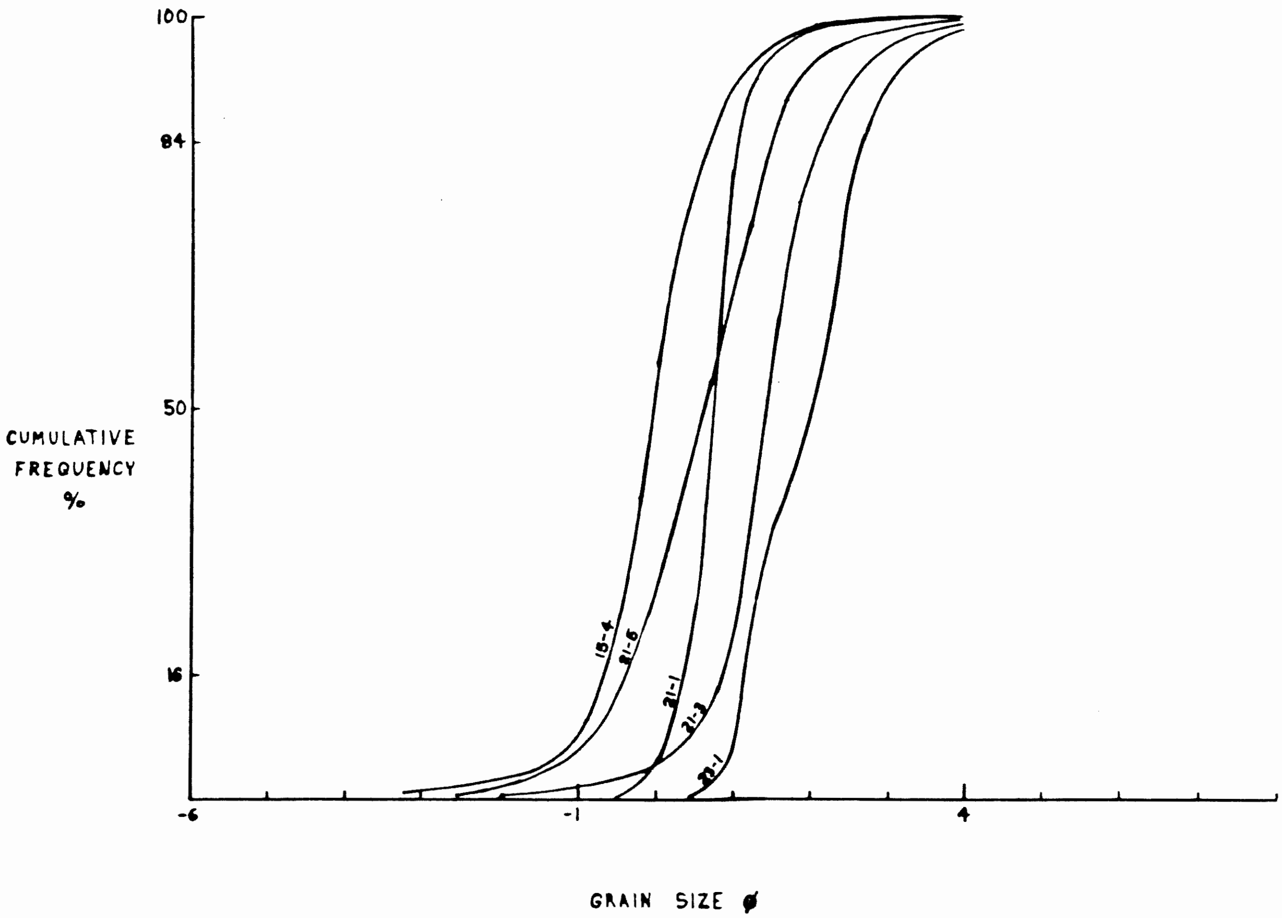


Figure 4. Cumulative frequency grain size distributions of five coarse sand samples.

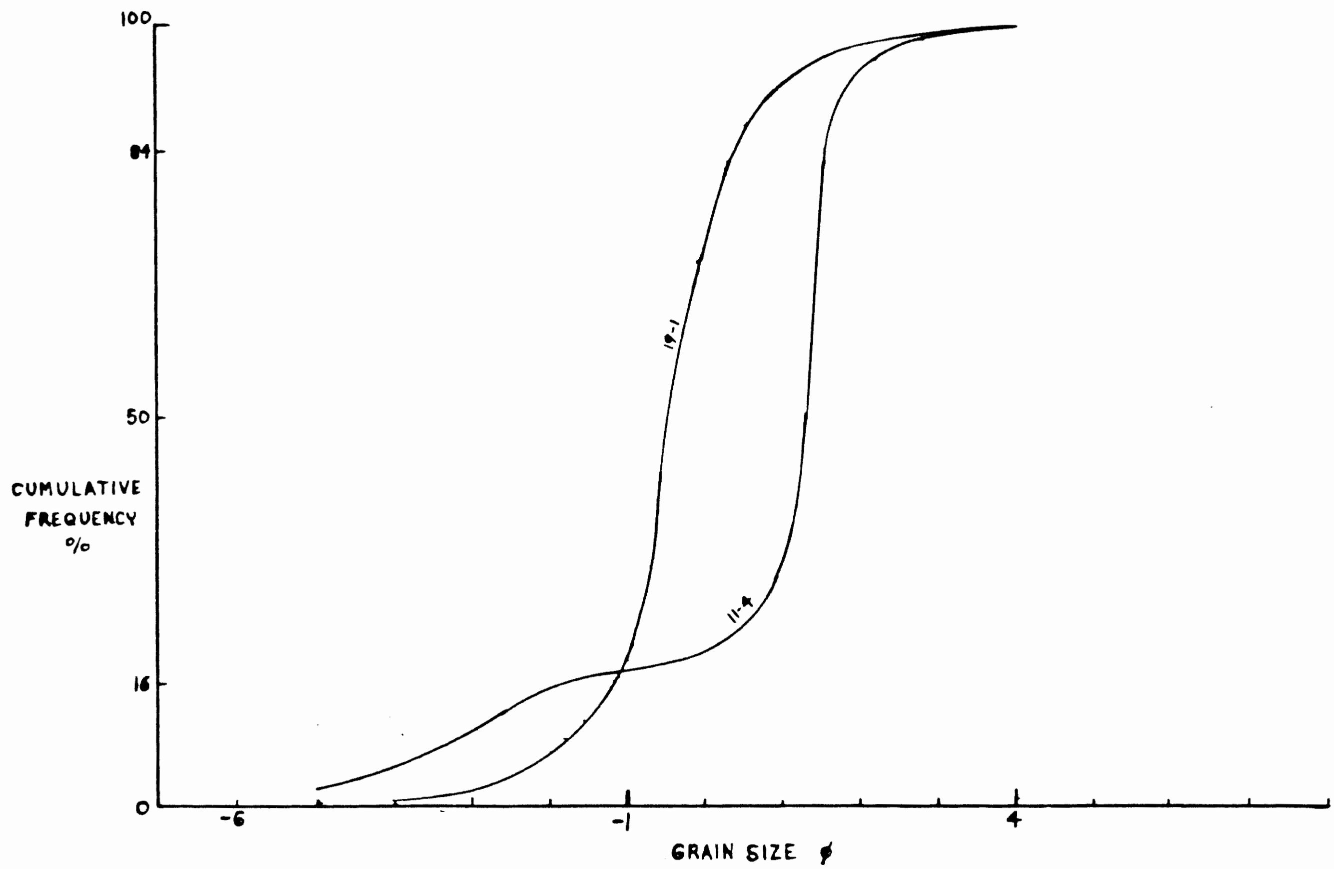


Figure 5. Cumulative frequency grain size distributions of two gravelly sand samples

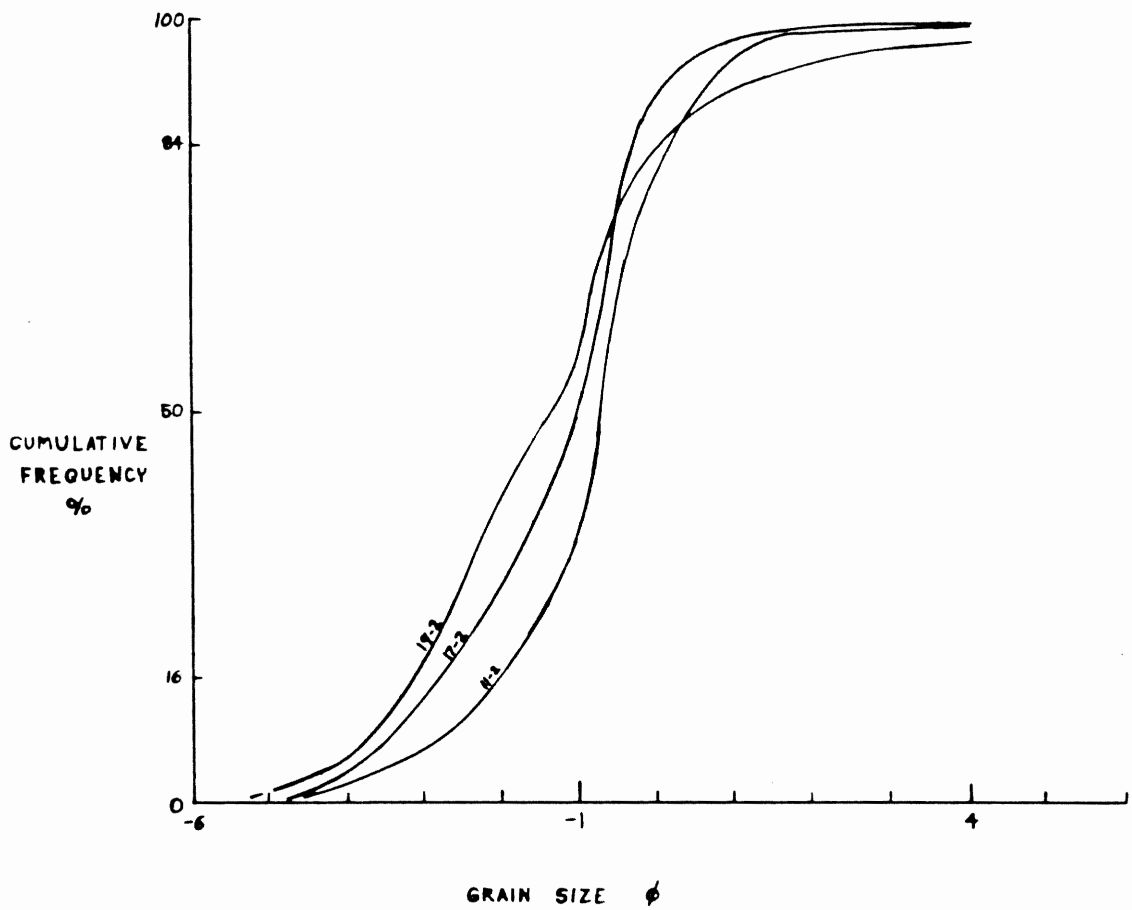


Figure 6. Cumulative frequency grain size distribution of three sandy gravel samples.

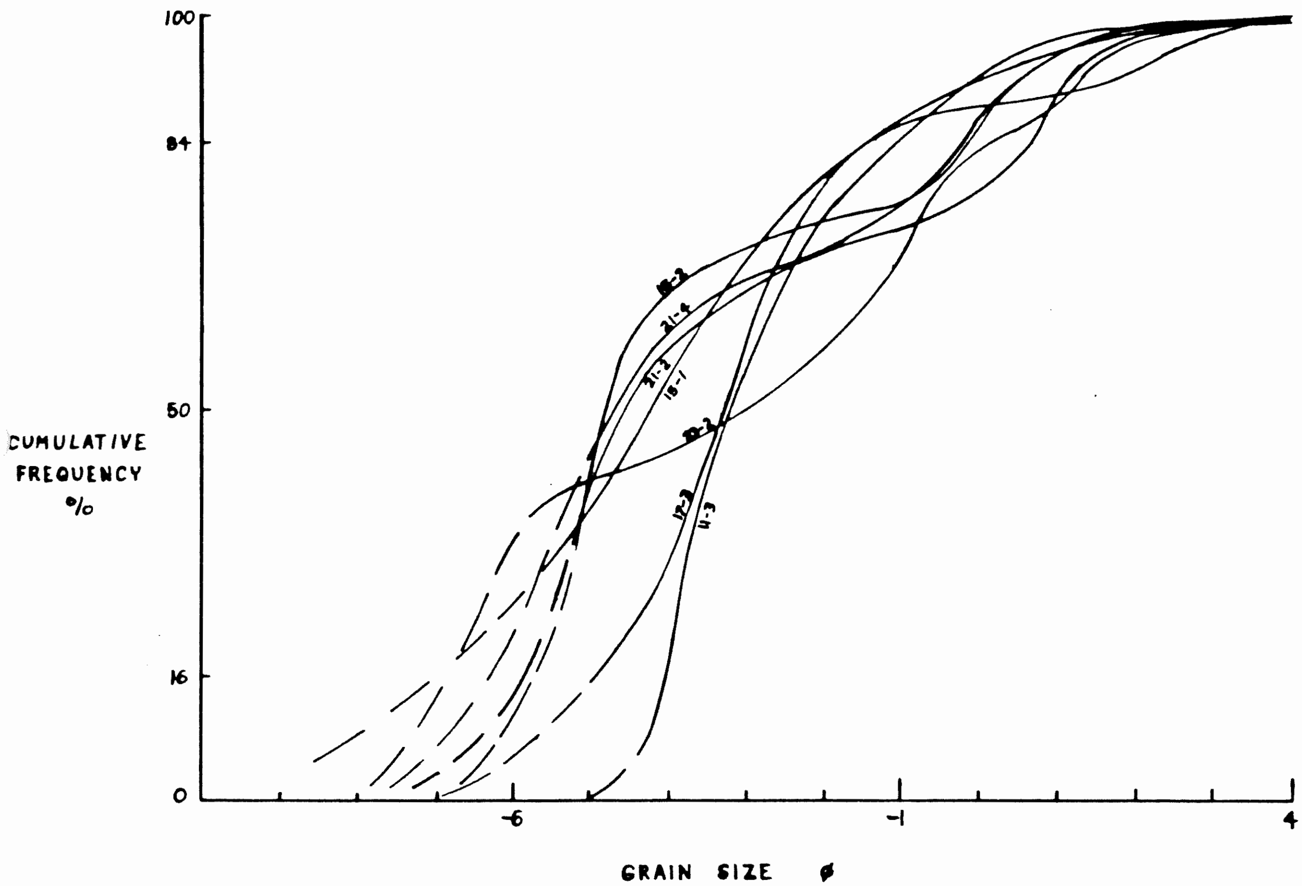


Figure 7. Cumulative frequency grain size distributions of seven coarse gravel samples.

Table 2. Grain size data for sand and gravel sediment types.

Sed. Type	Sample No.	Median Ø16	Ø50	Ø84	Mean	Sorting	Skewness	% Gravel : Sand : Silt & Clay
Coarse Gravel	17-3	-4.8	-3.3	-1.4	-3.2	1.7	0.11	86.2 : 13.0 : 0.8
	15-1	-6.9	-4.2	-1.3	-4.1	2.8	0.04	85.3 : 14.3 : 0.4
	11-3	-4.1	-3.2	-1.1	-2.8	1.5	0.40	82.8 : 16.3 : 0.9
	15-2	-5.9	-4.8	-0.1	-3.6	2.9	0.62	76.1 : 23.7 : 0.2
	21-2	-5.9	-4.6	-0.7	-3.3	2.6	0.61	75.4 : 24.1 : 0.5
	21-4	-6.3	-4.7	-0.3	-3.8	3.0	0.47	72.3 : 27.3 : 0.4
	23-2	-6.8	-3.0	-0.1	-3.3	3.3	-0.13	69.2 : 30.6 : 0.2
	average	-5.8	-4.0	-0.5	-3.4	2.5	0.30	78.2 : 21.3 : 0.5
Sandy Gravel	19-2	-3.1	1.4	0.2	-1.4	1.6	-0.03	57.1 : 40.6 : 2.3
	17-2	-2.8	-1.0	-0.4	-1.4	1.2	-0.50	51.5 : 48.1 : 0.4
	11-2	-2.1	-0.7	0.1	-0.9	1.1	-0.27	34.2 : 65.4 : 0.4
	average	-2.7	-1.0	0.0	-1.2	1.3	-0.27	47.6 : 51.4 : 1.0
Gravelly Sand	11-4	-1.7	1.3	1.6	0.4	1.7	-0.81	18.0 : 81.3 : 0.7
	19-1	-1.1	-0.4	0.3	-0.4	0.7	0.0	17.6 : 81.7 : 0.7
	average	-1.4	0.4	0.9	0.0	1.2	-0.41	17.8 : 81.5 : 0.7
Coarse Sand	15-4	-0.7	0.0	0.7	0.0	0.7	0.0	6.7 : 92.7 : 0.6
	21-5	-0.4	0.6	1.5	0.6	0.9	-0.05	5.8 : 92.0 : 1.2
	23-1	1.2	2.1	2.7	2.0	0.7	-0.20	0 : 98.6 : 1.4
	21-1	0.3	0.8	1.1	0.7	0.4	-0.25	0 : 99.8 : 0.2
	21-3	0.9	1.4	2.1	1.5	0.6	0.17	1.8 : 96.8 : 1.4
	average	0.3	1.0	1.6	1.0	0.7	-0.07	2.9 : 96.1 : 1.0

Table 2. (cont'd)

Sed. Type	Sample No.	Median Ø16	Ø50	Ø84	Mean	Sorting	Skewness	% Gravel : Sand Silt & Clay
Fine	11-1	2.4	2.9	3.6	3.3	0.6	0.17	0 : 89.8 : 10.2
Sand	17-1	1.8	2.4	4.0	2.7	1.1	0.45	0 : 83.8 : 16.2
	15-3	3.0	3.4	4.2	3.5	0.6	0.33	0 : 81.0 : 19.0
	average	2.4	2.9	3.9	3.2	0.8	0.32	0 : 84.9 : 15.1

Mean = $1/3\,(\text{Ø}16 + \text{Ø}50 + \text{Ø}84)$ (Folk and Ward)

Sorting = $1/2\,(\text{Ø}84 + \text{Ø}16)$ (Inman)

Skewness = $\dfrac{\text{Ø}16 + \text{Ø}84 + 2(\text{Ø}50)}{\text{Ø}84 - \text{Ø}16}$ (Inman)

Fine Sand

These sediments are red-brown to light brown and are composed primarily of moderately well-sorted, positively skewed, fine-grained sand. The overall grain size range is approximately from 1 phi to 6 phi. Stratigraphic units are characterized by sets of laminae and cross-laminae that range in thickness from 1 to 5 cm (Fig. 8). There are local occurrences of faults, sand dykes, muddy bands, and distorted lamination.

Coarse Sand

These sediments are composed of moderately well-sorted, positively skewed, medium to coarse grained sands, and have an overall grain-size range of approximately -3 phi to 5 phi. Colour is generally light brown to reddish brown, and grains are sub-rounded in shape. In some places sediments are stained orange if near the top of a section.

Stratigraphic units are characterized by planar and trough cross-bed sets up to 20 cm thick (Fig. 9), and 1 to 2 cm sets of cross-lamination. Some strata contain planar cross-beds that dip as much as 45^{o} (Fig. 10), and these may be interpreted as foreset beds. Clay lenses are also present.

In all sandy and gravelly strata, the bedding and cross-bedding is defined by layers of different-sized clasts and by the alignment of elongate grains.

Gravelly Sand

These sediments are reddish brown and consist of coarse sand with 10 to 20 percent fine gravel. They are moderately sorted and negatively skewed. The overall grain size range of the samples is from -5 phi to

Figure 8. Cross-laminae within fine sand in Spencer pit.

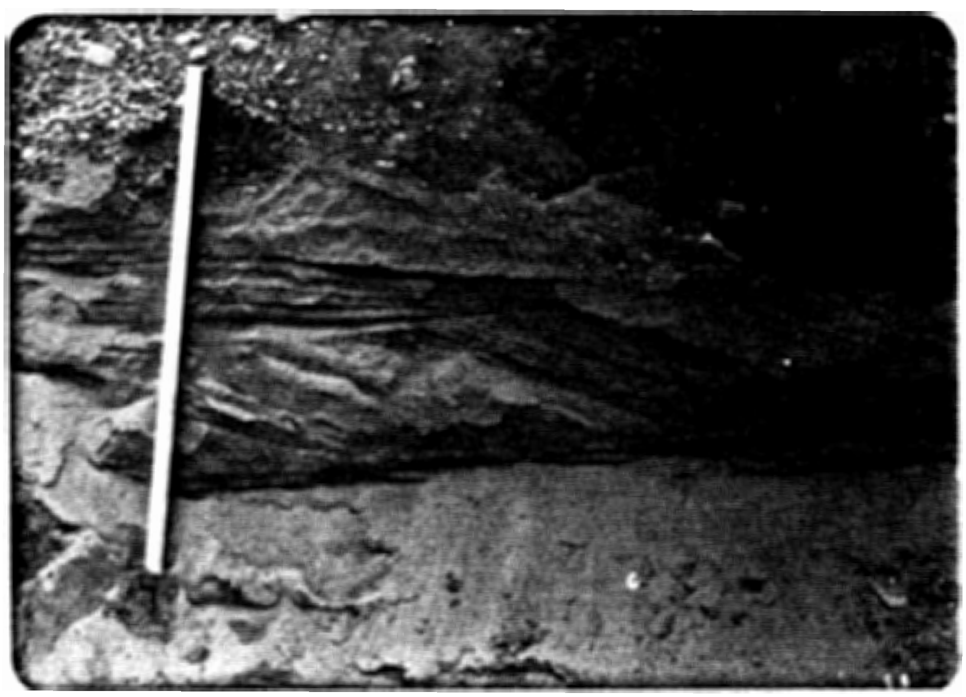


Figure 9. Trough cross-bed sets within coarse sand in Spencer pit.

4 phi. The clasts are commonly sub-rounded and range from spherical to tabular.

Stratigraphic units generally contain planar beds that range from 2 to 20 cm in thickness. Cross-stratified and massive strata also are present.

Sandy Gravel

These sediments consist mainly of grey to brown coarse sand and fine gravel. They are moderately sorted and negatively skewed, and the overall grain size range is from -5 phi to 3 phi. The largest clasts are supported by a matrix of sand and fine gravel. Coarse sand forms 40 to 65 percent of the samples with granules and pebbles making almost all the balance. Pebbles up to 5 cm commonly form less than 10 percent of the samples, and no cobbles or boulders are present. The clasts are sub-rounded to rounded and have varied shapes.

Stratigraphic units are massive or contain planar beds that range from 4 to 20 cm in thickness.

Coarse Gravel

These sediments are composed of fine to very coarse gravel, with minor coarse sand. They are poorly sorted and positively skewed. The overall grain size range of the samples is from -9 phi to 2 phi. Sixty(60) to eighty(80) percent of the sediments (by weight) are commonly pebble-sized or larger, and some strata contain up to 10 percent boulders. The largest boulder observed was 80 cm. in long axis.

The gravel samples show a bimodal grain size distribution. One grain size mode lies between -6 phi and -3 phi and a second between -2 phi and 2 phi. These two modes may be explained by the simultaneous deposition of sediments that were carried by two different modes of transport. The coarse gravel was carried by rolling and saltation along the bed; the sand and fine gravel that now composes the matrix was carried in suspension. The bimodal distribution of grain size results in very poor sorting. The sediments are matrix-supported, with clast-supported coarser units.

The matrix is greyish brown to reddish brown, whereas the coarser clasts range in colour because of their different compositions. The clasts have varied shapes and most are well-rounded.

Stratigraphic units of gravel are either massive or contain planar beds that range in thickness from 5 to 50 cm. Fining-up sequences (Fig. 11), and bands of boulders, cobbles and pebbles are commonly visible. Imbrication also occurs.

Figure 10 (left). Planar cross-beds within coarse sand in Spencer pit. Dip angle is up to 45°.

Figure 11 (right). Fining-up sequence within coarse gravel in Spencer pit.

Clast Composition

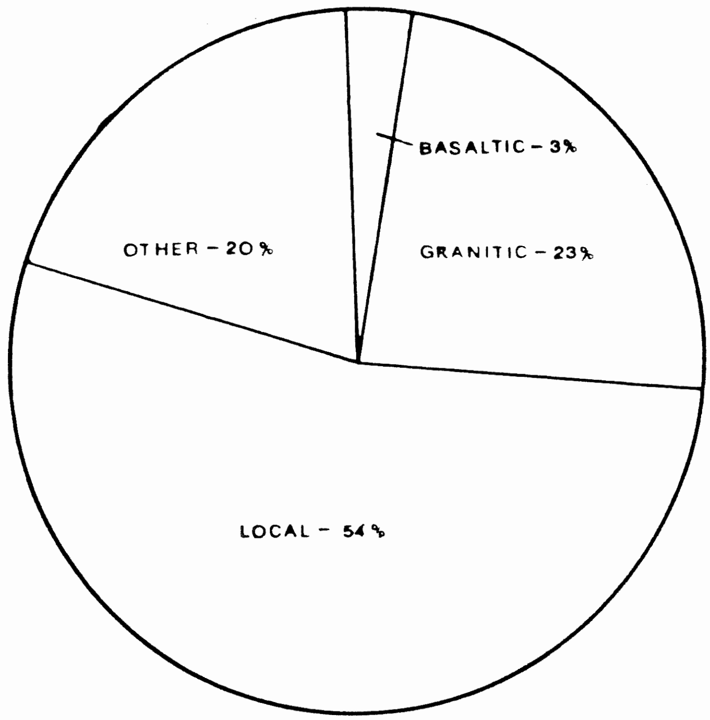
The relative proportions of four compositional categories were determined for two samples (Fig. 12). The categories were based on those used by Stea (1982) for his till compositional analyses:

1. basaltic
2. granitic
3. local
4. others

About 55 percent of the clasts are local Carboniferous sedimentary rocks from the Horton, Windsor, Canso and Pictou Groups, and Cambro-Ordovician metasediments from the Meguma Group. Rocks of these groups compose the bedrock that underlies the glaciofluvial deposit. It is difficult to tell which stratigraphic group an individual clast comes from, so the groups are classified together.

Basaltic clasts are rare (less than 8 percent) and granitic clasts are common (about 20 percent). Both are easily recognizable rock types and their origins can be traced from their mineralogical compositions. The basaltic clasts are derived largely from the North Mountain basalts. Granitic clasts could originate from the Cobequid Highlands or the South Mountain.

Cobequid Highland granitoids are characteristically rich in pink potassium feldspar (Stea, personal communication, 1983), and contain hornblende but no muscovite (Stea, 1982). Muscovite occurs at South Mountain but hornblende is absent. Most of the observed granitic clasts contain hornblende, no muscovite and abundant pink potassium feldspar, indicating a likely Cobequid Highland origin.



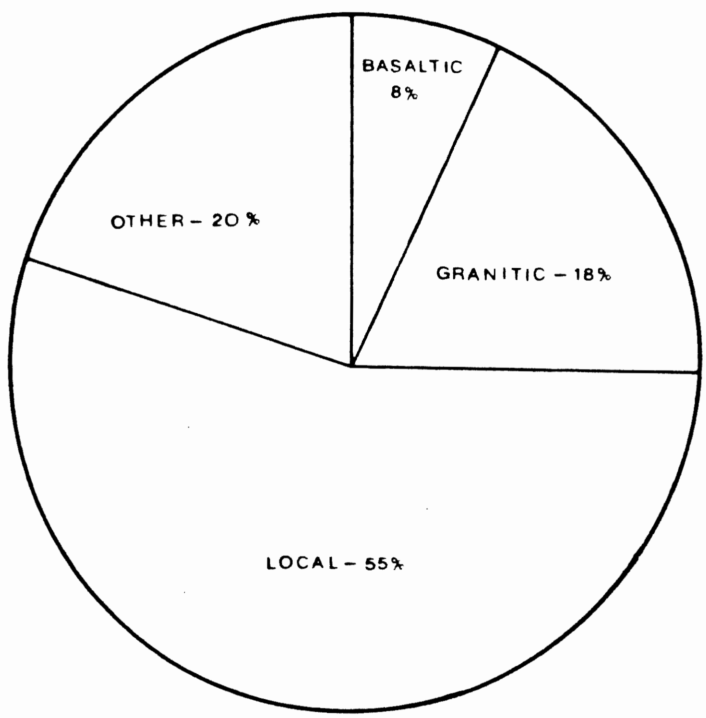


Figure 12. Proportions of clasts in four compositional categories; 144 clasts were sampled from Spencer pit (above diagram); 135 from Nova Scotia Sand and Gravel pit (below).

About 20 percent of the clasts were classified as "others". They include quartz, mafic schists, breccias and unidentifiable clasts.

Degree of Consolidation

The deposits are mainly unconsolidated; however, small portions have been cemented by precipitation of carbonate and iron oxide between the clasts.

Carbonate-cemented masses are found in the Spencer, Babcock and Davis pits. They are generally several metres in diameter and do not appear to be restricted to particular stratigraphic units. The carbonate cements gravelly and sandy beds, and was probably derived from dissolution of Windsor Group carbonates, which are common in the sediments and the local bedrock. Glacial meltwaters or later groundwaters contained carbonate material in solution and this material was later precipitated between the clasts. These waters would not have been limited to particular stratigraphic units.

In the Davis pit there is one bed of sand cemented by iron oxide (Fig. 13). It is about 15 cm thick, extends laterally up to 20 metres, and is within one metre of the section top. The bed is black where fresh and weathers yellow. Minor quantities of this cement is also present in the Spencer pit.

Chapter 4. SEDIMENT DISBRIBUTION AND STRATIGRAPHY

Spencer Pit

The glaciofluvial sediments of the Spencer pit are a prominent east trending ridge. The measured stratigraphic sections are from 5 to 8 m in thickness along the central core of the pit, but the overall thickness of the deposits decrease towards the ends and sides so that some of the exposed dections along the flanks are only 2 m thick. Much of this ridge has now been extracted, especially at the eastern and where few good sections could be measured.

The sediments are stratified in alternating layers of the six sediment types described in the previous chapter. Coarse gravels and coarse sands are the most common and silt and clay the least common. In general, the central core is composed of relatively thick, alternating strata of coarse gravel to coarse sand (Fig. 14), whereas the flanks are composed of coarse sand, fine sand, silt and clay alternating with thinner gravelly strata. The sediment distributions are summarized in Figure 15, and their relations are now described in further detail:

Silt and Clay

Stratigraphic units range from 5 to 100 cm in thickness, and most are between 10 and 20 cm thick. They commonly have gradational basal contacts underlain by sandy units, and abrupt erosional upper contacts overlain by sandy or gravelly units. These sediments are much more prevalent in the flanks of the deposit than in the core, but are overall the least common sediment type and also have the thinnest strata.

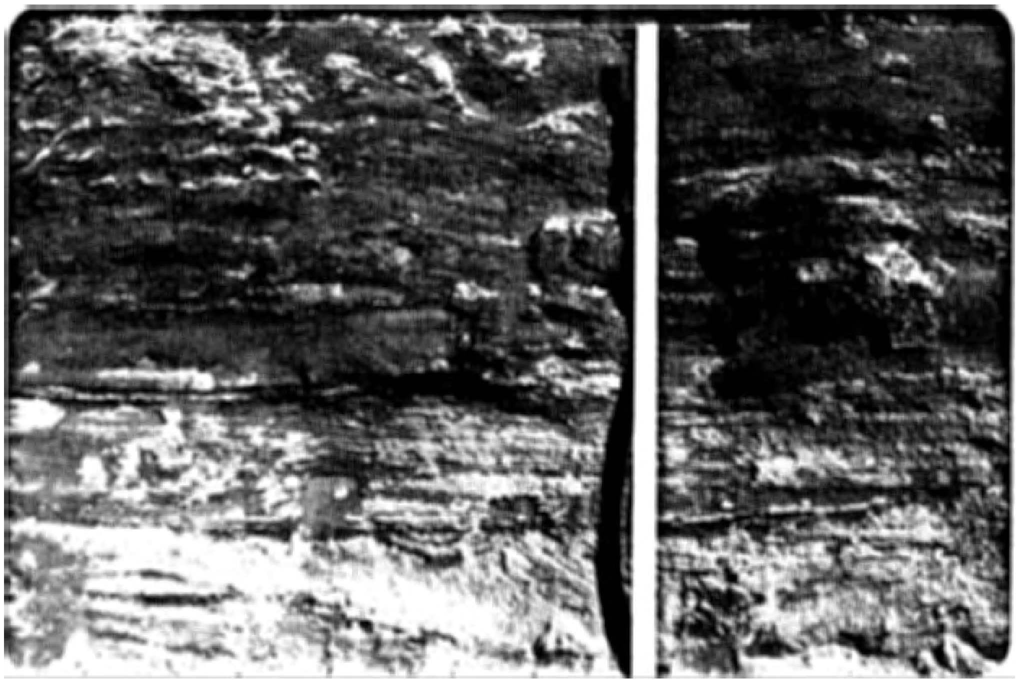


Figure 13. Sand bed cemented by iron oxide in Davis pit.

Figure 14. Alternating strata of coarse gravel, sandy gravel and coarse sand in Spencer pit core.

	SEDIMENT TYPE	DISTRIBUTION
Increased Sorting ↓	Coarse gravel Sandy gravel	common in core (mainly eastern half), minor in flanks
	Gravelly sand Coarse sand	common in core (mainly western half), common in flanks
	Fine sand Silt and mud	minor in core, common in flanks

Figure 15. Distribution of sediment types in Spencer pit.

Fine Sand

Stratigraphic units range from 15 to 210 cm in thickness; most are between 30 and 90 cm thick. They occur most commonly along the flanks of the deposit, in many cases at the top of sequences. The units that occur in the core usually have erosional upper contacts and are overlain by gravelly material.

Coarse Sand

Stratigraphic units are abundant and range from 5 to 280 cm in thickness, with most being between 40 and 200 cm. They occur most abundantly and are thickest in the western half of the pit core. In many cases they are part of overall fining-up sequences. The strata commonly have gradational (locally erosional) basal contacts and are underlain by gravelly material. In some places they are overlain by finer material with gradational contacts, but more commonly by gravelly material with erosional contacts.

Gravelly Sand

Stratigraphic units range in thickness from 15 to 270 cm, and most are between 35 and 100 cm thick. They are thickest and most common in the core of the pit, especially at the western end. The core strata commonly have gradational basal contacts and are underlain by coarser gravels. They are usually either overlain by coarser material or else lie at the top of a sequence. The strata at the flanks commonly have erosional basal contacts underlain by finer sediments, and commonly are overlain by sandy or silty material with gradational contacts.

Sandy Gravel

Stratigraphic units range in thickness from 30 to 130 cm and are found as both relatively thick strata along the core of the deposit and as minor strata along the flanks. The core units are underlain either by finer or coarser gravels with gradational contacts, or by sandy material with erosional contacts. They are usually overlain gradationally by coarse sands or coarse gravels. The strata along the flanks are commonly underlain erosionally by sandy units.

Coarse Gravel

Stratigraphic units range in thickness from 10 to 400 cm, but most are between 40 and 200 cm thick. Coarse gravel and coarse sand have the thickest, the most abundant, and the most widespread strata in the Spencer pit.Coarse gravel units are thickest and most abundant in the core, especially in the eastern half. They commonly have erosional basal contacts and are underlain by finer gravels and coarse sands, or else are at the base of the measured sections. They commonly have gradational upper contacts and are overlain by sands and finer gravels.

Lateral Variation and Continuity of Strata

Several stratigraphic units are continuous laterally for up to 200 metres, although inferences can be made beyond these distances. Four major stratigraphic divisions can be traced east-west through much of the pit core (Fig. 16). The lowest is composed mainly of coarse sand, and is 200 cm thick at the western end of the pit. This is overlain by a thick (up to 400 cm) stratigraphic unit of coarse gravel, which is in turn overlain by a second sandy unit 100 to 270 cm thick. Another coarse gravelly stratum overlies the second sandy unit at the eastern

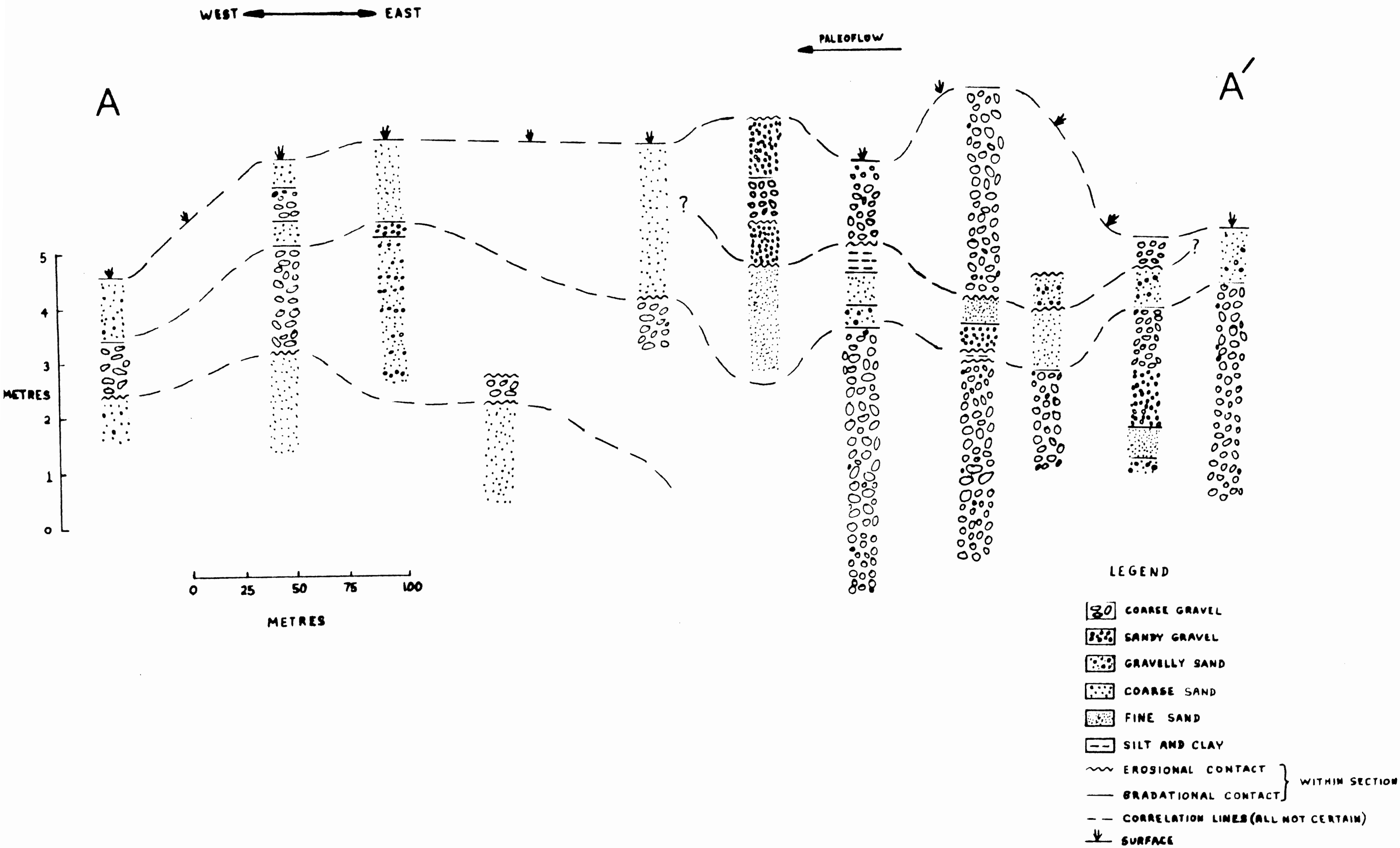


Figure 16. Longitudinal section A-A' (on Fig. 19) through central core of Spencer pit. Vertical exaggeration is 25.

end of the deposit.

The gravels tend to become thinner and finer grained towards the west, whereas the sands tend to thicken.

Sections along the core of the pit are thickest, best exposed, and easiest to correlate. Correlation over large distances and along the flanks of the deposit is hindered by the large lateral variation in lithology and thickness of certain strata, and because in places slumps and faults distort and offset beds.

All beds tend to thin towards the flanks, and the gravels become finer grained or pinch out completely (Figs. 17 and 18).

Other Pits

The sediments are extracted only in areas where they have been deposited in sufficiently thick and wide "beads". These large local accumulations can be separated by hundreds of metres where the deposits thin and narrow and are difficult to follow in the field or on a topographical map. It is therefore impossible to correlate strata from different pits.

The Spencer pit represents one 'bead' in the deposits, the Babcock and Davis pits together constitute one or two, and the Nova Scotia Sand and Gravel pit may contain several overlapping beads, although here the deposits are much more continuous.

Although the other pits are several kilometres apart, the sediment types and the stratigraphic distribution within them are remarkably similar to those observed in the Spencer pit. Points of similarity are:

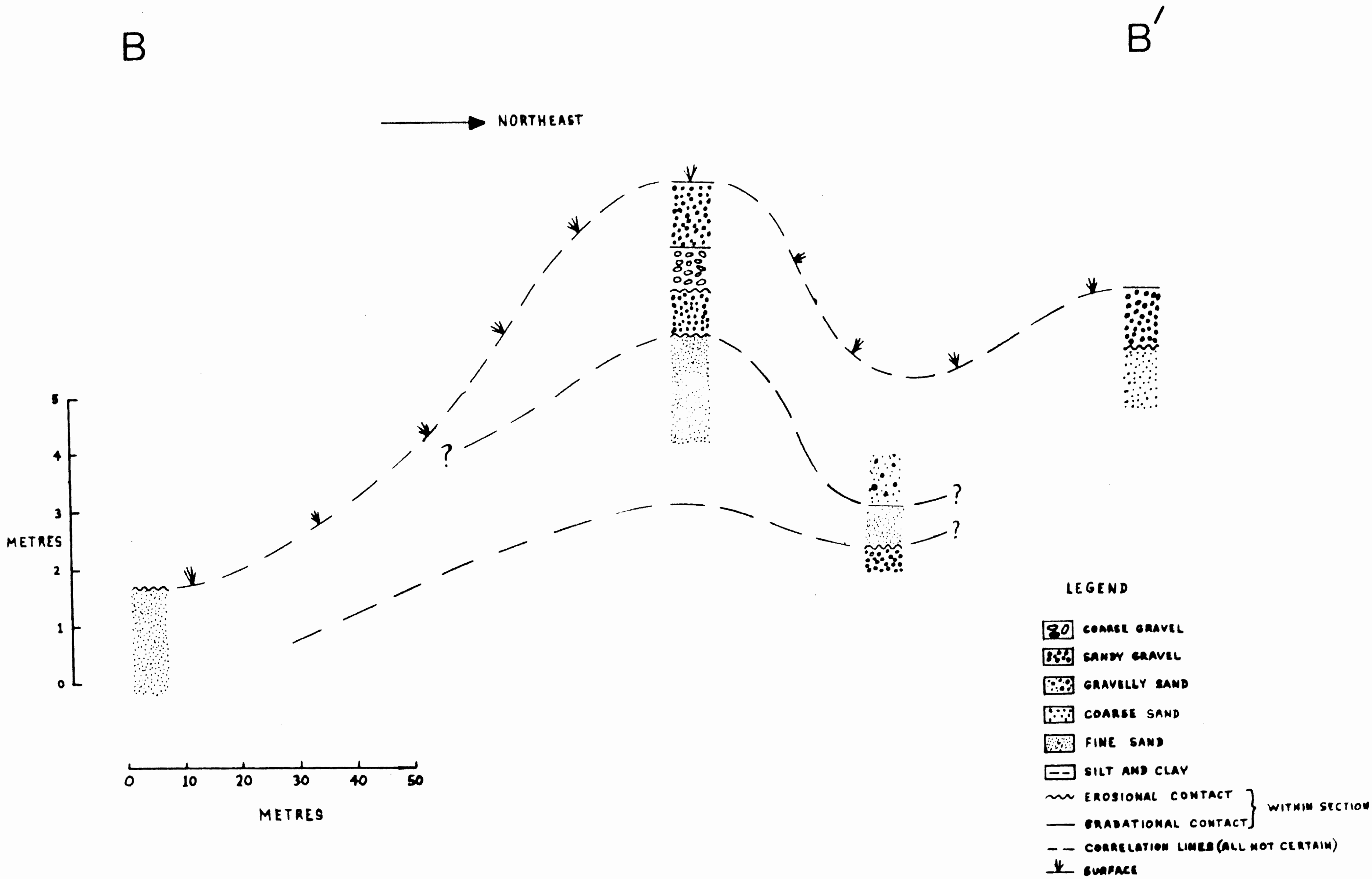


Figure 17. Cross-section B-B' (on Fig. 19) through Spencer pit. Vertical exaggeration is 10.

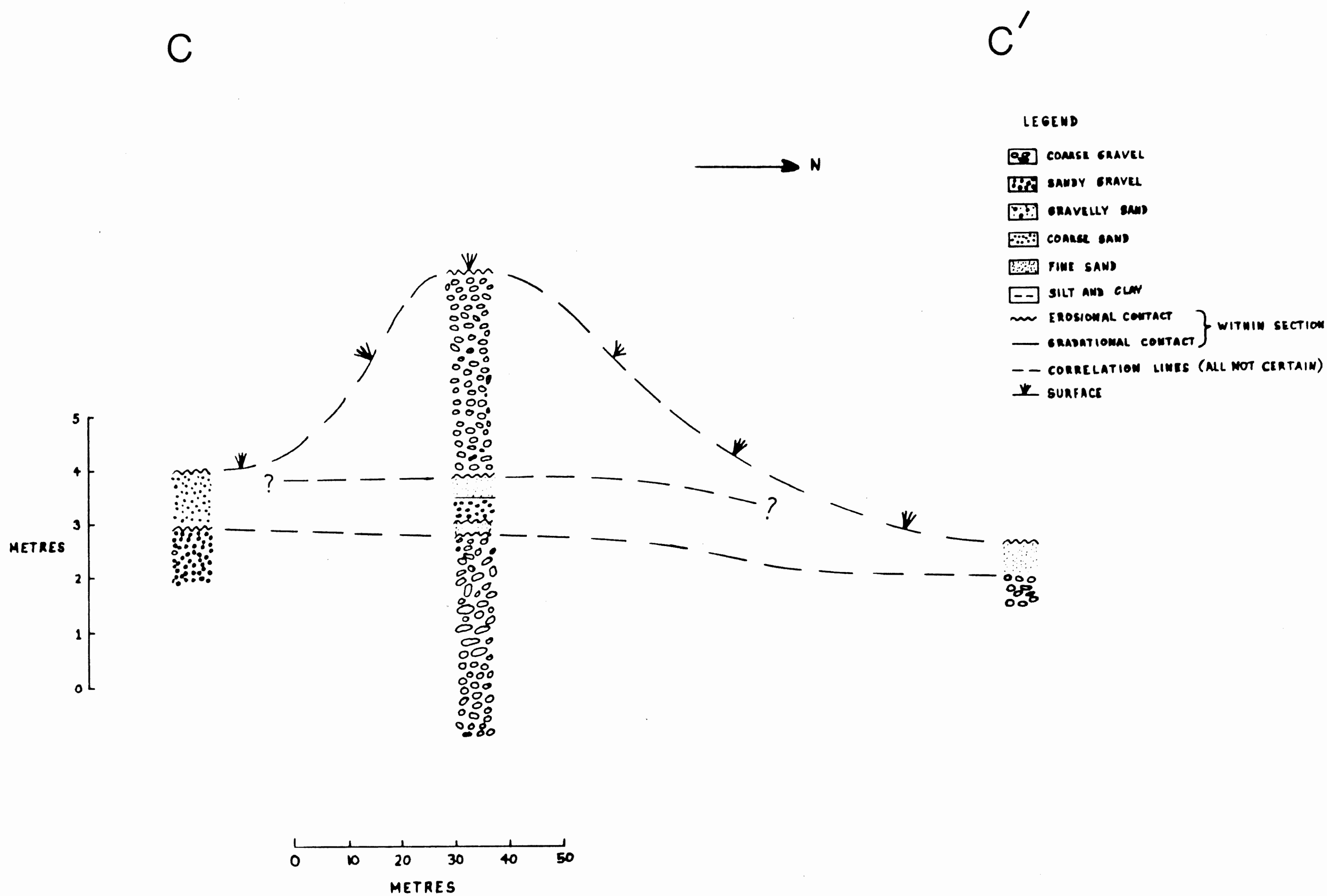


Figure 18. Cross-section C-C' (on Fig. 19) through Spencer pit. Vertical exaggeration is 10.

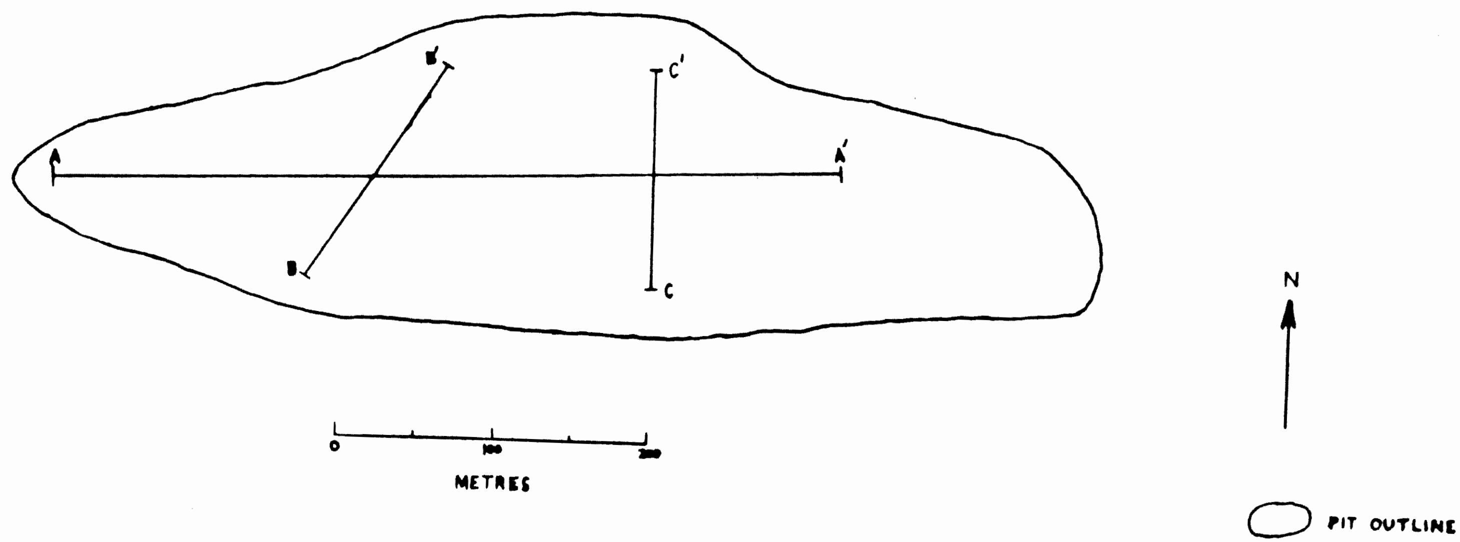


Figure 19. Location of longitudinal section A-A' and cross-sections B-B' and C-C' in Spencer pit.

1. The six sediment types are present in approximately the same proportions as in the Spencer pit.

2. All sections are stratified, with thick gravels grading towards the flanks to thinner sandy beds.

3. Two stratigraphic sections measured along the central core of the Davis pit, and one in the core of the Babcock pit, show two to three thick (well over 100 cm) strata of coarse gravel separated by thinner finer-grained beds. Basal strata of cobble and boulder gravel are overlain by interbedded silts, sands, and fine gravels, which in turn are overlain by more coarse gravels (Fig. 20).

4. The main gravelly strata in the Davis pit and the Nova Scotia Sand and Gravel pit are laterally traceable for up to 200 metres.

5. The flanks of the above two pits are composed predominantly of sand and gravelly sand (Fig. 21). The sands contain planar bedding (Fig. 22), planar and trough cross-bedding, and cross-lamination. Strata are up to several metres thick and are laterally traceable for up to 150 m.

6. The western end of the Nova Scotia Sand and Gravel pit is composed mainly of sand. These sandy strata contain climbing ripples (Fig. 23) and possible varves (Fig. 24). These consist of thin (under 1 cm) silty bands occurring at regular 3-5 cm intervals within fine sand.

7. Normal faults (Fig. 25) and slumps are present in the exposed sections.

This last point leads into the differences observed in the other pits:

1. The Babcock pit contains more faults and had steeper-sided margins than other areas.

2. In cross-section, the main thick gravels and the interbedded sands and silts in the core of the Babcock pit all reach their highest

Figure 20. Section in core of Davis pit, with thick gravel layers and thinner sands. Compare to Fig. 14.

Figure 21. Sands and gravelly sands along north flank of Davis pit. Section approximately 200 m north of Fig. 20 section.

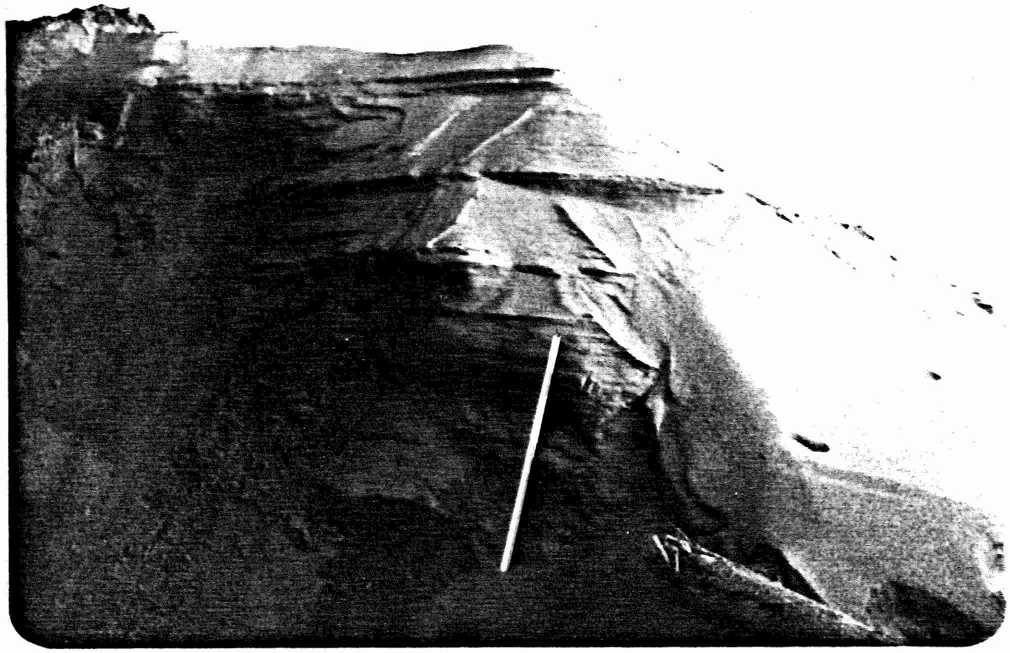


Figure 22. Planar beds within coarse sand along flank of Davis pit.

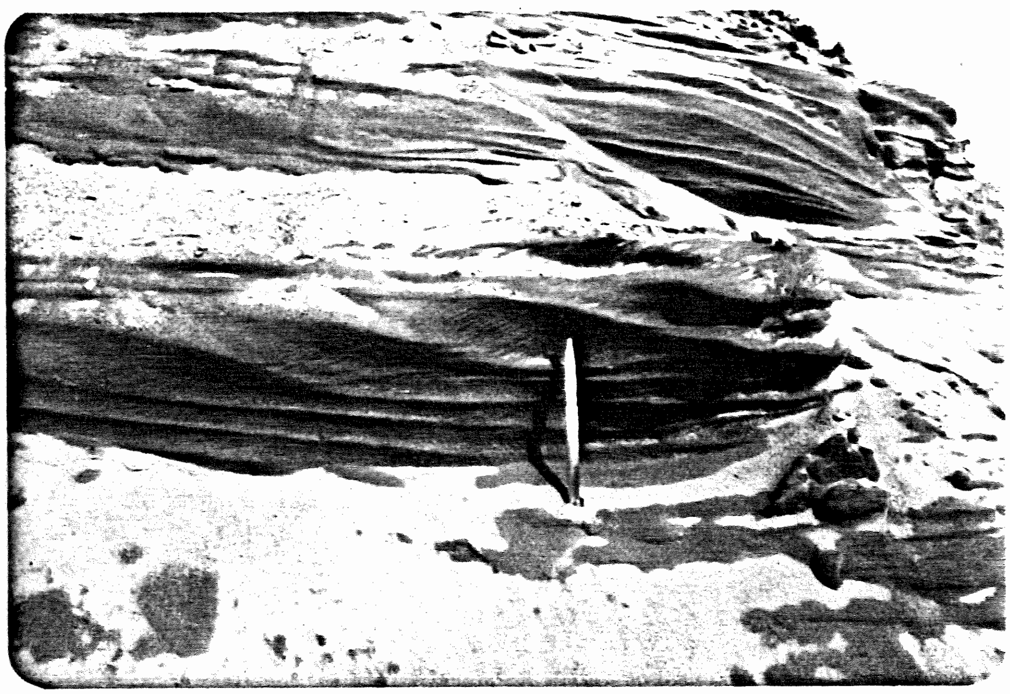


Figure 23. Climbing ripples within sand at western end of Nova Scotia Sand and Gravel pit.

Figure 24. Thin, regularly spaced silt laminae within fine sand in Nova Scotia Sand and Gravel pit. The laminae probably represent varves.

Figure 25. Normal fault in Davis pit.

elevations in the pit center, and dip off steeply towards the flanks, persisting to the outer margins.

3. The deposits overall are thicker, wider and more continuous than at the Spencer pit. The central cores of the Babcock and Davis pits are up to 10 m thick, and the Davis pit is up to 500 m wide. The Nova Scotia Sand and Gravel pit has maximums of 15 m core thickness and 1 km width.

The similar sediment types and stratigraphic distributions in all the pits imply similar processes of formation. Typical distributions within a bead are shown in Figure 26.

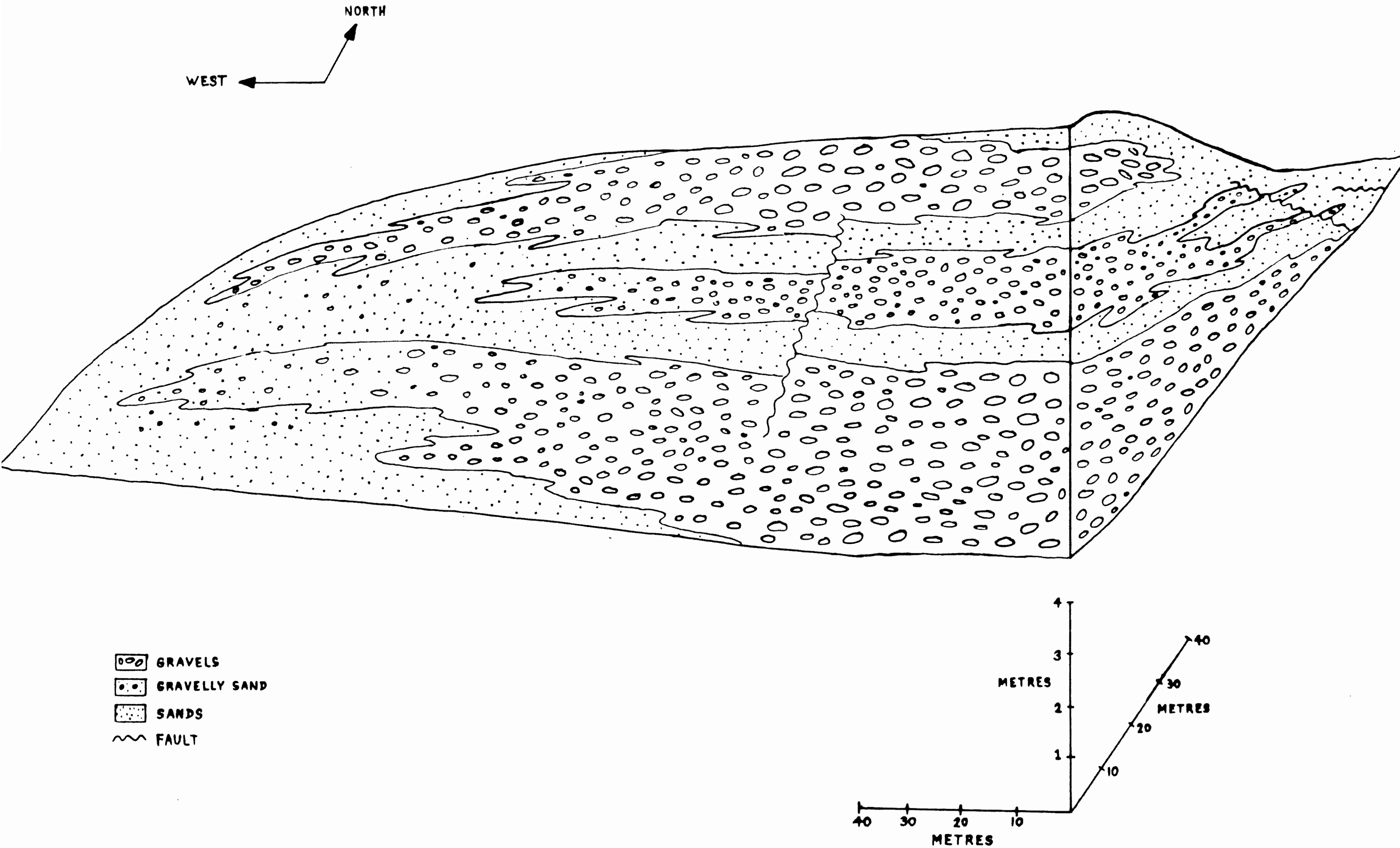


Figure 26. Summarized and idealized cross-sections parallel and perpendicular to central core of typical "bead" in deposit.

Chapter 5. FLOW PATTERNS

Flow Velocities

Knowing the grain sizes and typical sedimentary structures of each sediment type, it is possible to calculate the minimum depositional flow velocities required to transport the clasts (Fig. 27). Silt and clay particles are under 4 phi (0.03 mm in diameter), and the sediments are finely laminated, suggesting flow velocities of 20-25 cm/sec. Fine sand and coarse sand grains average 3 phi (0.12 mm in diameter) and 1 phi (0.5 mm) respectively. Fine sands commonly contain ripple cross lamination, suggesting flow velocities of 30-60 cm/sec; coarse sands typically contain large-scale trough cross-beds, implying flow velocities of 50-100 cm/sec. Gravelly sand and sandy gravel grains average 0 phi (1mm in diameter) and -1 phi (2 mm) respectively. Gravelly sands commonly contain planar beds, implying an even flow over a plane bed and flow velocities of 100-200 cm/sec; sandy gravels are massive or contain planar beds, suggesting flow velocities of 100-300 cm/sec (Fig. 28).

Coarse gravels are different because they have a bimodal distribution, with one mode at -4 phi to -5 phi (16-32 mm in diameter) and the other near 0 phi (1 mm). Flow velocities were at least 300 cm/sec, with the coarse gravels being transported as bedload and by saltation, and the finer sediments by suspension (Fig. 28).

It is important to remember that these are experimentally-attained theoretical values for the minimum depositional velocities (Fig. 27) or transport velocities (Fig. 28) of specific particle sizes. Actual flow velocities may have been greater, or may have varied with flow depth.

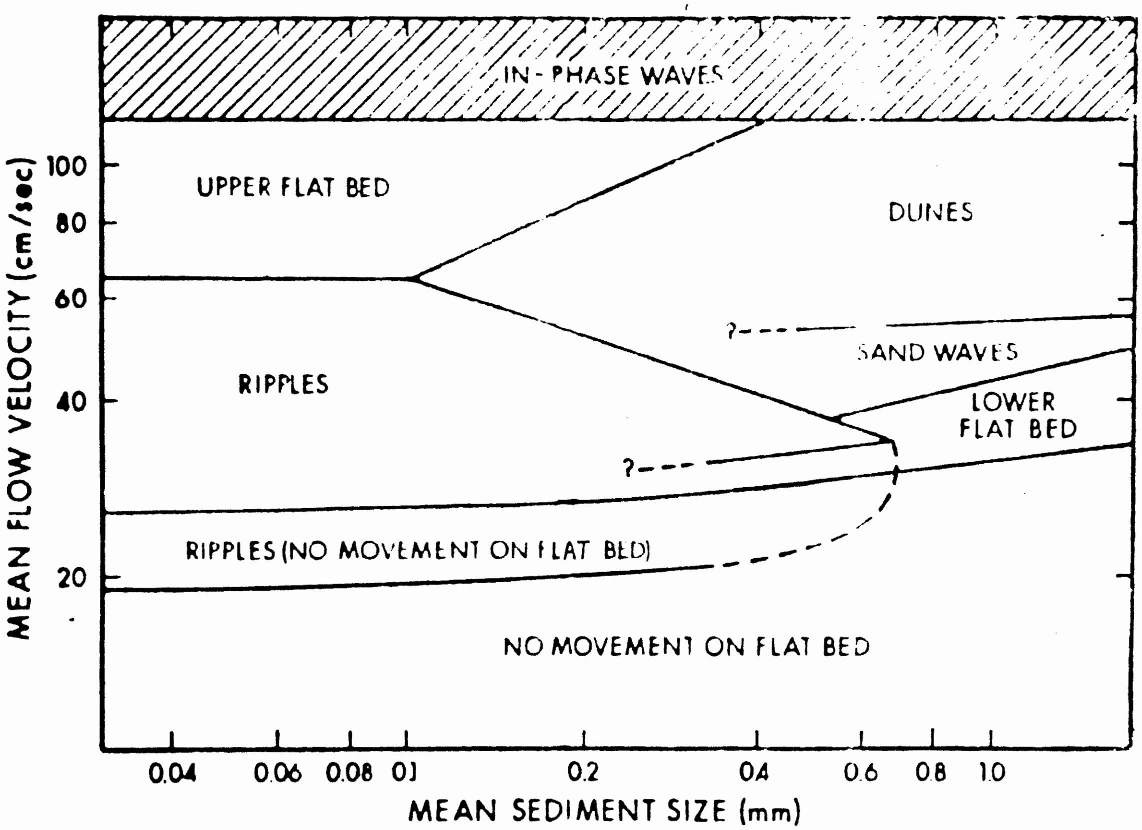


Figure 27. Bedforms in relation to grain size and velocity. From Church and Gilbert (1975) after Harmes *et al.* (1975).

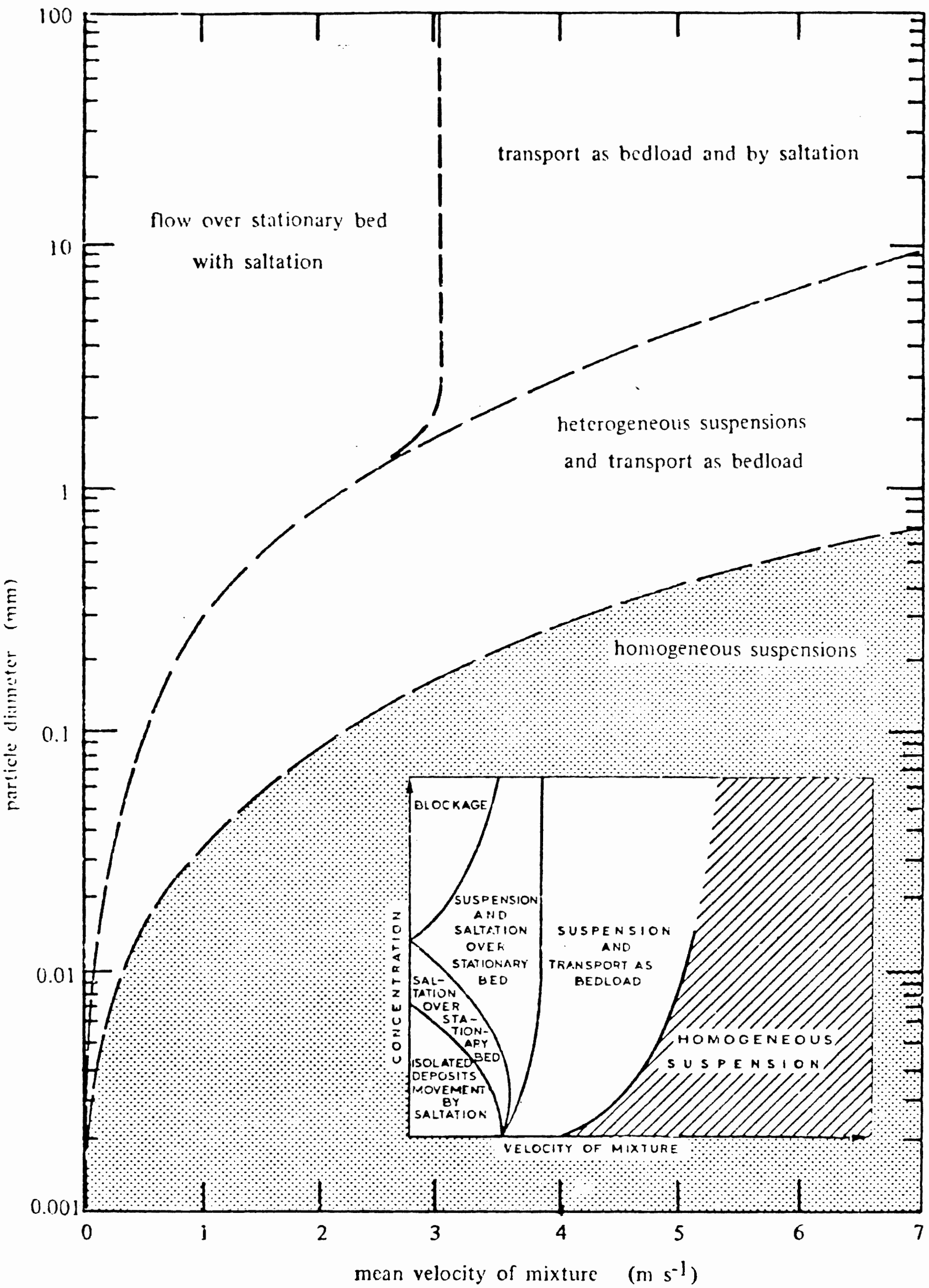


Figure 28. Principal transport regimes for sediment (S.G. = 2.65). From Church and Gilbert (1975).

Flow Directions

A predominantly westward flow with a large amount of scatter was evident from paleocurrent directions measured in both the Spencer pit and the Nova Scotia Sand and Gravel pit (Fig. 29). These measurements are supported by the compilations of Stea and Hemworth (1980).

Different flow directions can be measured within one stratum, suggesting that flow directions fluctuated significantly over a relatively short time and distance.

Directional measurements were taken only from sandy strata, which contain cross-stratification. There are no measurements for coarser sediments formed in higher energy flow regimes that would be more representative of the main flow.

Flow Variations and Sediment Disbribution

The numerous changes in clast size and sedimentary structures both vertically and laterally through the sequences imply sudden and frequent flow energy variations. The finer grain sizes along the flanks of all the pits and at the west end of the Spencer pit represent lower flow energies than do the coarser grained strata along the central cores of the deposits. The centralized locations of the gravels suggest that the high flow regimes were laterally restricted, and that the lower energy regimes deposited the finer grained sediments downstream from and marginal to the locus of high energy flow.

Coarse-grained strata are commonly erosionally based and grade up into finer-grained strata. The nature of these contacts imply that the flows tended to occur in pulses, with each pulse eroding the top of the bed below and then depositing coarser grained sediments. As the flow

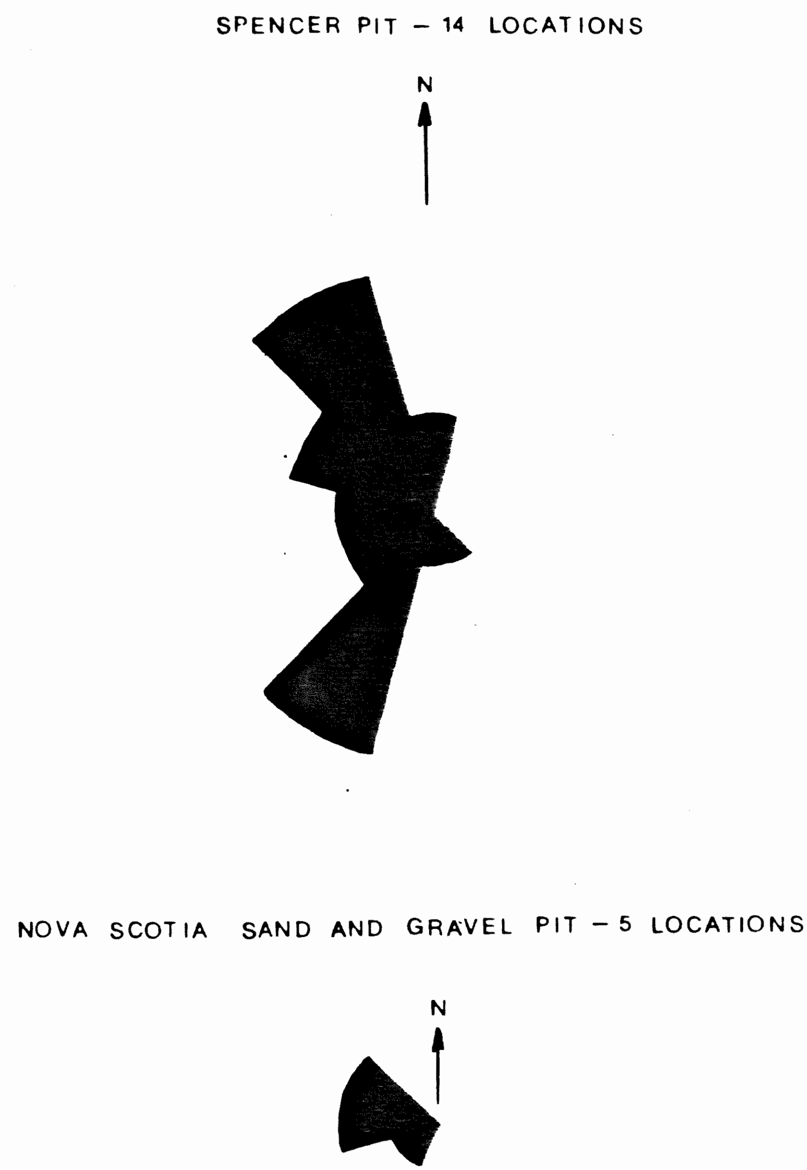


Figure 29. Paleocurrent directions measured from cross-beds and cross-lamination.

energy decreased, finer sediments were deposited higher in the sequence.

The thin sands and silts that interrupt the thick coarse gravels along the central cores of the deposits represent rapid drops in energy level. Because they occur interspersed with the gravels through the entire deposit, and at any one locality occur at regularly spaced intervals, they must represent regular drops in energy levels, or else temporary shifts in stream location.

Chapter 6. INTERPRETATION AND DISCUSSION

Environment of Deposition

Because the deposits are in the form of an irregular, partially discontinuous ridge that extends for many kilometres, and because they contain a mixture of sands and gravels with abundant water-worn, rounded cobbles and boulders, they accurately fit the description of an esker (Roland, 1982, p. 74-76). The sediment ridges are too extensive to be a series of isolated kame mounds, and could not be kame terraces because they are not piled up against a valley side. They also could not be outwash deposits because of their steep sides and high content of coarse gravel.

Beyond the general acceptance of eskers as ice-contact glaciofluvial features, little concensus exists with respect to theories of origin. It seems certain that environments of esker deposition vary considerably in detail, although all are thought to have been deposited by a stream confined on both sides by ice. Three basic models of esker sedimentation have been proposed by Banerjee and McDonald (1975): open channel (fluvial), tunnel, and deltaic. In all three models the sediments are thought to have been deposited either at the ice front or within three kilometres of it.

The deltaic model is probably the most commonly used in recent esker literature. According to Banerjee and McDonald (1975), deltaic eskers are characterized by separate or overlapping beads that were deposited annually as fans in the water body at the mouth of a subglacial tunnel. These beads consist of cobble and pebble gravel at the proximal end of the bead intertonguing over a few metres in a downstream direction with ripple laminated fine sand, units of structureless fine and medium sand, and graded beds that were deposited by a rapidly decelerating flow. A large variability in paleocurrent directions within these eskers was also found by Banerjee and McDonald (1975).

The sediment distribution within the Spencer pit fits best the deltaic model. Paleocurrent directions, although predominantly westward, are greatly scattered in the Spencer pit as well as in the Nova Scotia Sand and Gravel Pit. The gravelly core of the Spencer pit probably represents the area of immediate high-energy discharge from the mouth of a subglacial stream, and is possibly topset beds. The coarse gravels grade towards the flanks and westward (downcurrent) into finer gravels and sands. These consist of sets of steeply-dipping planar cross-beds (foreset beds) and trough cross-beds, and finely laminated silts and sands that may represent bottomset beds. This spreading of the finer suspended sediments in lower energy flows away from the mouth of the subglacial tunnel results in the large variation in current directions and in better sorted distal material. Comparable sediment distributions within eskers have been described by Saunderson (1975) and Banerjee and McDonald (1975).

The interbedded sands and silts within the gravelly central core represent either sudden, recurring (possibly annual?) drops in flow velocity, or else temporary shifts in the stream locations. The apparent 'pulses' of sedimentation, characterized by erosionally based gravel beds that grade upwards into finer gravels and sands, may represent the shifting of deltaic channels. The energy level at a particular location would gradually decrease as the stream wandered away from that point.

The cross-beds and cross-laminae and the presence of kettle lakes and swamps adjacent to the Spencer pit and other parts of the esker suggest that the sediments were deposited into ponded glacial meltwater. The presence of several faults (mostly normal) and sediment slumps suggest ice contact at the time of deposition (McDonald and Shilts, 1975). However, because there are relatively few faults in the Spencer pit, it is likely that the deposits were not let down from high in a melting glacier, but were instead deposited directly onto the ground as a delta lobe. Only where the sediments were supported against a wall of melting ice did faults later form.

Because the spencer pit is isolated, it probably represents an esker 'bead'. Beaded eskers consist of separate, regularly spaced, roughly conical hills of sediment that are 100 to 200 m in diameter and 5 to 15 m high (Banerjee and McDonald, 1975).

Towards the east, the deposits are thicker, wider and more continuous. They do not fit the general description of a beaded esker, although several overlapping deltaic beads could take this shape.

In the Babcock pit, the many faults, the height and steepness of the ridge, and the lateral continuity of the beds in cross-section are best explained by sedimentation within a subglacial tunnel. Tunnel-deposited eskers usually are steep sided, contain many faults and have persistent beds both longitudinally and in cross-section (Banerjee and McDonald, 1975). However, they also contain little fine sand and silt and have low variability in paleocurrent directions (Banerjee and McDonald, 1975). More detailed work in the area would be needed to confirm this explanation.

Because no detailed stratigraphic sections were measured in the Nova Scotia Sand and Gravel pit, it is difficult to make any qualitative depositional interpretations. However, it appears evident that high energy proximal gravels in the central core grade towards the flanks and the west into lower energy distal sands, similar to the situation in the Spencer pit. The thin, regularly spaced silt and clay beds within the fine sands at the western end may represent distal lake bottom rhythmites of the deltaic model described by Banerjee and McDonald (1975).

Eskers deposited in open channels commonly contain large backsets related to antidunes (Banerjee and McDonald, 1975). These are not found in the area.

Eskers are time-transgressive, with the downstream portion being the oldest (Banerjee and McDonald, 1975). Therefore, the first glaciofluvial sediments in the area to be laid down were those at the western end of the deposit, on the eastern slopes of the Rawdon hills. More sediments would have been deposited successively farther eastward as the glacier melted back. The flow direction of the sediments was towards the west, even though the glacial retreat was towards the east. This explains how the sediments could apparently be flowing westward uphill over the Rawdon hills, because the sediments higher on the slope were deposited before the sediments near the bottom. Because deposition rates fluctuated greatly, the rate of glacial retreat must also have varied.

Relation to Pleistocene Deglaciation

Because no major till sequences or erosional surfaces overlie the glaciofluvial sediments, they must be the youngest deposits in the area. They were formed during the last Pleistocene glacial retreat, which probably occurred between 14,000 years B. P., when the ice apparently retreated from the Fundy coast (Roland, 1982), and 11,000 years B. P., when the local ice caps had melted (Roland, 1982).

Nielsen (1976) suggested that the Nova Scotian mainland was probably mainly deglaciated by 12,000 years B. P.. However, local ice caps possibly remained over the Eastern Cobequids and the Antigonish Highlands (Prest, 1970), and over the South Mountain (Hickox, 1962), up to or more recently than 12,000 years ago. The predominantly westward paleocurrent directions indicate that the esker sediments flowed from the east towards the west. This and the similarity in composotion of the occasional granitic clasts with the Cobequid granites indicates that the ice flow originated to the east or north-east. This agrees with the suggestion of Stea (1982) that around 12,000 yeass ago a late westerly flow of ice from a possible Antigonish Highland source produced, along with some till, many eskers and ice-contact features trending east-west in Hants County. It was probably during the stagnation and eastward retreat of this ice flow that the Upper Nine Mile River esker deposits were formed.

Chapter 7. CONCLUSIONS

1. The glaciofluvial sediments are the youngest deposits in the study area.

2. The sediments are almost entirely unconsolidated; local occurrences of carbonate-cemented and iron oxide-cemented sediments are present however.

3. Approximately 55 percent of the clasts are derived from local bedrock (Carboniferous sedimentary rocks and Meguma Group metasediments).

4. Most granitic clasts are compositionally similar to the Cobequid granitoids.

5. Paleocurrent directions trend westward with high variability.

6. Six sediment types are present throughout the deposit. Each sediment type has a characteristic range of grain sizes and bedforms. These range from finely laminated silt and clay to massive coarse gravels. Coarse gravels and coarse sands are the most abundant types.

7. The central core of the Spencer pit is composed mainly of thick alternating strata of coarse gravel to coarse sand. Gravels tend to grade into sands towards the western end and towards the flanks of the pit. All strata thin and fine towards the flanks.

8. This westward and outward gradation probably resulted from deposition from the mouth of a westward flowing, laterally restrictive, high-energy subglacial stream. Finer sediments were deposited downstream and marginal to the proximal coarse gravels. The Spencer pit therefore represents a deltaic esker bead.

9. Gravel strata in the core contain thin sand and silt interbeds. Flow energy variations were therefore frequent and drastic. It is difficult to tell whether these changes were seasonal or due to shifting channels.

10. The Spencer pit is generally representative of the entire deposit. The other pits studied contain the same sediment types, have the same stratified nature, and show similar gravel to sand transitions from their cores outwards. Westward gravel to sand gradations are also present in other pits.

11. Minor local variations indicate slight differences in mode of deposition. The deposits are thicker, wider and more continuous towards the east; they are therefore less beaded. More faults, steeper margins, and a greater lateral continuity of strata in cross-section are present in the Babcock pit; it is possible that these sediments were deposited within a subglacial tunnel.

12. The sediments were deposited during the stagnation and retreat of a late (12,000 years B. P.?) ice flow that probably originated from the Antigonish or Cobequid Highlands. The ice would have retreated towards the east; therefore, the eastern sediments are youngest.

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Figure 1. Location of glaciofluvial deposits and excavated areas near Upper Nine Mile River, Nova Scotia. Data assembled from field observations, aerial photos and topographic maps.