1

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

National Library
of Canada

Bibliothèque nationale
du Canada

Canadian Theses Service

Service des thèses canadiennes

Ottawa, Canada
K1A 0N4

NOTICE

The quality of this microform is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

Reproduction in full or in part of this microform is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30, and subsequent amendments.

AVIS

La qualité de cette microforme dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de qualité inférieure.

La reproduction, même partielle, de cette microforme est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30, et ses amendements subséquents.

**AN EXAMINATION OF TWO TECHNIQUES
TO DETERMINE THE ORIGIN OF SOIL-SIZED PARTICLES
ON ALPINE SLOPES IN THE DUKE VALLEY
SOUTHWEST YUKON**

by

James E. Howes, C.D., r.m.c., B.A., M.A., p.f.s.c.

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of

Master of Arts

Department of Geography

Carleton University

Ottawa, Ontario

15 July 1991

© copyright

1991, James Howes

National Library
of Canada

Bibliothèque nationale
du Canada

Canadian Theses Service Service des thèses canadiennes

Ottawa, Canada
K1A 0N4

The author has granted an irrevocable non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of his/her thesis by any means and in any form or format, making this thesis available to interested persons.

The author retains ownership of the copyright in his/her thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without his/her permission.

L'auteur a accordé une licence irrévocable et non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de sa thèse de quelque manière et sous quelque forme que ce soit pour mettre des exemplaires de cette thèse à la disposition des personnes intéressées.

L'auteur conserve la propriété du droit d'auteur qui protège sa thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

ISBN 0-315-70897-2

Canada

The undersigned recommend to the Faculty of Graduate Studies
and Research acceptance of the thesis

**"AN EXAMINATION OF TWO TECHNIQUES TO DETERMINE
THE ORIGIN OF SOIL-SIZED PARTICLES
ON ALPINE SLOPES IN THE DUKE VALLEY
SOUTHWEST YUKON"**

submitted by James E. Howes, C.D., r.m.c., B.A., M.A., p.f.s.c.
in partial fulfilment of the requirements for
the degree of Master of Arts

.....
Thesis Supervisor

..... Acting
Chair, Department of Geography

Carleton University

17 July 1991

ABSTRACT

The origin of soil-sized particles on the western slopes of the Kluane Ranges in the Duke Valley, southwest Yukon, were investigated. A total of 48 soil samples were extracted along twelve transect lines over a thirty-kilometre stretch of the right bank of the upper Duke River. For purposes of comparison, a further seven samples from known loess deposits were extracted from sites along the left bank of the Slims River and the southeastern shoreline bluffs overlooking Kluane Lake. Both sets of samples were subjected to x-ray diffraction and particle size distribution analyses.

The data indicate that neither loess nor fine ablation till has made a detectable contribution to the soil-sized materials on these slopes. The evidence suggests that the parent materials are the products of local bedrock weathering. Little if any sorting takes place during downslope movement.

ACKNOWLEDGEMENTS

I would like to acknowledge with gratitude the support and assistance of my mentors, friends, and colleagues who contributed so much to the successful completion of this project. Firstly, I would like to thank my thesis co-supervisors, Professor J. Peter Johnson, Jr., of the Carleton University Geography Department and Dr. Chang Wang of the Agriculture Canada Land Resource Centre Institute for their patient tolerance of my floundering and their insightful advice when I became entangled in snares of my own making. I owe a special note of thanks to Dr. Wang for placing the laboratory resources of the Land Resource Research Centre at my disposal.

Much of the success in this field-oriented research project was due in large part to the enthusiastic support which I received from friends and colleagues in the Yukon. I would like to acknowledge with gratitude the support of Superintendent Dwayne West of the Kluane National Park Reserve and Deputy Superintendent Ray Brenaman who generously provided helicopter lift in and out of the park at critical times throughout the project, and without whose support I could not have succeeded. I would also like to thank Mr. Andy Williams, Kluane Lake Research Station Manager and fixed-wing alpine pilot *extraordinaire* whose skill at knap of the earth flying enabled us to reconnoitre a feasible overland route through the Kluane Ranges into the upper Duke Valley.

In Ottawa I was supported by three very professional lab technicians:

Mr. Bernard Sheldrick and Mr. Gordon Scott of the Land Resource Research Centre, and Mr. Ronald Conlon of the Carleton University Earth Sciences Department. I would like to thank Mr. Sheldrick for allowing me the run of his laboratory for six weeks and for his coaching in the art of processing large sample batches. I am also grateful to Mr. Scott who performed the x-ray diffraction tests on my clay fraction samples, and who gave my work priority over his own, and to Mr. Conlon who did the same with the whole sample batches, and who found a way to write off the expense when I ran out of funds.

Finally, I would like to express my heartfelt thanks to my wife, Magdalena, who endured my bouts of absentmindedness and obsessive behaviour with cheerful forbearance, and who gave me the love and support without which I could not have completed this project. It is to her that I dedicate this work.

J.E.H.

TABLE OF CONTENTS

	Page
Acceptance Sheet	ii
Abstract	iii
Acknowledgements	iv
Table of Contents	vi
List of Tables	viii
List of Maps	ix
 Chapter 1: Introduction	 1
Physiography and Climate	1
Hypotheses	7
Field Methodology	10
 Chapter 2: X-ray Diffraction Analysis	 15
Introduction	15
X-ray Diffraction Signature Comparison	16
A-score Validation	21
Whole Sample Analysis	24
Clay Fraction Analysis	26
Summary	30
 Chapter 3: Particle Size Distribution	 32
Introduction	32
Laboratory Procedures	33
Graphical Analysis	36
Visual Examination	39

Statistical Parameters	40
Known Loess Deposits	41
Duke Valley Materials	45
Summary	51
 Chapter 4: Conclusions	 52
Origins	52
Downslope Movement	59
Diffraction Signature Comparison	61
 Refererces	 64
 Appendix A: Loess Particle Size Distribution Curves	 69
 Appendix B: Duke Valley Particle Size Distribution Curves . . .	 77

LIST OF TABLES

Table	Description	Page
2.1	Selected Peaks for Signature Comparison	18
2.2	A-scores from Slims Valley Samples	22
2.3	Quartz to Calcite Ratios	23
2.4	Intratransect Whole Sample A-scores	24
2.5	Intertransect Whole Sample A-scores	25
2.6	Intratransect Clay Fraction A-scores	28
2.7	Intertransect Clay Fraction A-scores	29
3.1	Conversion of Metric Diameters to Phi Sizes	38
3.2	Percentage Composition of Loess Deposits	42
3.3	Statistical Parameters of Loess Deposits	43
3.4	Duke Valley Graphic Mean Values	44
3.5	Duke Valley Standard Deviation Parameters	46
3.6	Duke Valley Inclusive Skewness Parameters	46
3.7	Duke Valley Graphic Kurtosis Values	47

LIST OF MAPS

Map	Description	Page
1.1	Location of Kluane National Park	2
1.2	Main Physiographic Features	3
1.3	Location of Study Areas	10
1.4	Layout of Duke Valley Transects	11
1.5	Location of Known Loess Deposits	13

CHAPTER 1

INTRODUCTION

This study deals with the origin and movement of soil-sized (i.e., ≤ 2 mm diameter) particles on the slopes of the Duke Valley in the southwestern Yukon Territory. The Duke Valley study area lies entirely within the boundaries of Kluane National Park (see Map 1.1). The study was conducted over a two-year period with the field work taking place during the summers of 1989 and 1990. The laboratory analysis was carried out at the Carleton University Geotechnical Science Laboratories and the Agriculture Canada Land Resource Research Centre in Ottawa during the fall and winter of 1990/1991. Funding was provided by Carleton University's Northern and Native Studies Committee in the form of two annual Northern Science Training grants.

Physiography and Climate

The Duke Valley is a U-shaped glacially scoured alpine feature which trends northwesterly for approximately 35 km between the Kluane Ranges

Map 1.1: Location of Kluane National Park, Southwest Yukon.

on the east and the Donjek Range on the west and lies within the rain shadow of the Icefield Range of the St. Elias Mountains (see Map 1.2). The valley is drained by the Duke River whose principal source is a small valley glacier approximately six kilometers in length which is fed by a series of cirque glaciers on the southeastern flank of the Donjek Range. The river flows through its valley for approximately 36 kilometres before cutting through the Kluane ranges to the Duke Depression (as defined by Rampton, 1981). From there, the river flows northward for a distance of roughly 25 km to the Kluane River which it enters as a tributary at a point approximately 3.5 km downstream from the latter river's principal source, Kluane Lake. Over its 61 km length, the Duke River descends from an elevation of 1900 meters a.m.s.l. at its source to an elevation of 785 meters at its mouth.

Map 1.2: Major physiographic features in the vicinity of the study areas.

The Duke Valley, whose width ranges from three to four kilometers, is considerably more confined than its major neighbours. The Donjek Valley, which lies on the western side of the Donjek Range and runs parallel to the Duke, ranges in width from 10km to 15km in most places. The Donjek River's source is a series of larger valley glaciers the first of which has its terminus at an elevation of 1675m. The Duke's other neighbour, the Slims Valley, begins at the terminus of the Kaskawulsh Glacier at an even lower elevation of 800m. From there, the Slims River flows for approximately 22 km northeasterly to its mouth at the southwestern end of Kluane Lake. In terms of width, the Slims Valley is of the same order of

magnitude as the Donjek.

Approximately 10 km to the east of the Duke Valley, the surface drops precipitously into the Shikwak Trench, a northwest-southeasterly trending feature some 10 km in width, which separates the St. Elias Mountains from the westernmost fringes of the Yukon Plateau. A major feature in the trench is Kluane Lake, four to seven kilometers in width and 55 km in length. The Slims River is the principal source of its waters. Its outlet is the Kluane River which, as mentioned earlier, is joined in turn by the Duke River some 3.5 km downstream from the lake.

Lying in the rain shadow of the St. Elias Mountains, the area has a climate which is both semi-arid and cold. The 1974 edition of the National Atlas of Canada (Fremlin, 1974) gives the mean annual precipitation for Kluane Lake as only 300 mm, the mean January daily temperature as -27.5°C and the mean July temperature as 12.5°C . It is instructive to note that the mean annual precipitation rate for Ottawa is three times higher, the mean January daily temperature is 17.5°C warmer, and mean July temperature is 7.5°C warmer. The existence of scattered permafrost is reported throughout the Shikwak Trench.

In the Duke Valley conditions are even more extreme, and this writer encountered permafrost regularly even on the lower slopes at depths of less than a meter. The presence of permafrost at such shallow depths on the steep alpine slopes has given rise to widespread solifluction. Indeed the solifluction lobe is the dominant landform on these slopes. This writer estimates that approximately 80 percent of the surface area of the alpine slopes within the Duke Valley study area is covered by solifluction lobes. A typical lobe is one to two meters in length, approximately a meter in width, and is roughly 50 cm thick at the downslope end.

During the July-August 1990 field season this writer made twice-daily observations of wind directions in the Duke Valley study area, and when conditions permitted, noted the movement of upper winds by the direction of cloud movement. No clear cut diurnal or katabatic patterns were detected. Low level valley winds usually blew from either the up valley or down valley direction, frequently reversing direction during the day but followed no discernible pattern. It is of interest to note that P.G. Johnson (1975) likewise detected no katabatic or diurnal wind pattern in the vicinity of Grizzly Creek, a tributary of the Duke River adjacent to the study area. Despite the absence of such patterns, winds in the Duke Valley were often strong enough to transport loess, and, on some days, loess clouds were whipped up to a height in excess of 100m above the floodplain. On these occasions, the loess clouds were sometimes dense enough at ground level to completely obscure the opposite bank of the river.

During the late Pleistocene, a series of glacial events did much to shape the topography of the area and determined the nature of its surficial deposits. There is some evidence of even earlier glaciations in the tills east of Kluane Lake (Denton and Stuiver, 1967) which can be dated as far back as 100,000 years B.P. These workers have also determined that subsequent glacial events occurred in the following sequence: the Icefield Glacial from *circa* 49,000 B.P. to 37,700 B.P., the Kluane Glacial from *circa* 30,100 B.P. to between 12,500 and 9780 B.P., and the Neoglacial, a relatively minor glacial readvance, which began *circa* 2640 B.P. and, according to Borns and Goldthwait (1966), reached its limit *circa* 1836 A.D.

In terms of till deposits on the current landscapes in the area, the Kluane Glacial was by far the most important of these events. Rampton (1981), who conducted a major air photo study of the area, states: "Most sections of Pleistocene sediments in Kluane National Park consist of

interbedded gravel and till. Generally only one till is exposed, and it is presumably of Kluane age." Rampton also reports that during this glaciation, all major valleys were filled with ice with most mountains protruding as nunataks. Denton and Stuiver (1967) determined that the ice surface reached an elevation of about 1860m at the southern end of Kluane Lake from whence it flowed northward through the Shakwak Trench. At the intersection of the Donjek River and the trench, they maintain the ice surface was at a somewhat lower elevation of 1520m. From his study, Rampton (1981) determined that a major glacier flowed through the Duke Valley into the Shakwak Trench. During his trip into the Duke Valley in 1990, this writer conducted a survey of the trimlines in the valley and concluded that the ice surface had reached as high as 300m above the current floodplain to an elevation of 1950m.

Following the Hypsithermal interval, the Neoglacial advance commenced around 2640 B.P as mentioned previously. In the case of the major valley glaciers, the advance was appreciable. The Kaskawulsh Glacier, for instance, advanced at least 21.9km to its present terminus (Denton and Stuiver, 1967), and Bostock (1969) maintained that it advanced several hundred meters further to completely block the Slims Valley. In the Duke Valley, however, the Neoglacial was a relatively minor event. The limit of the Neoglacial advance is clearly defined by a terminal moraine located approximately 1.5km beyond the present terminus. If one assumes that the Duke Valley glacier completely disappeared during the Hypsithermal interval, then the maximum readvance would still have been no more than 7.5km. Its thickness was probably no greater than the 90m which has been calculated to be the maximum probable thickness for small valley glaciers in the area (Crossley and Clarke, 1972).

As a consequence of this history of glaciations, both the Donjek

and Slims Valley contain substantial deposits of loess. These deposits and their history have been well described by Denton and Stuiver (1966), Borns and Goldthwait (1966), Hughes *et al.* (1972), Nickling (1972), Denton and Karlén (1973), and Rampton (1981). These workers have determined that there were two periods of deposition. The first of these occurred between 12,000 and 9,000 years ago towards the end of the Kluane Glacial, and the resulting deposit is known as "Kluane loess." A glacial readvance and reactivation of the outwash which commenced between 2,600 and 3,000 years ago resulted in the deposition of "Neoglacial loess." In some areas, particularly in the vicinity of active valley trains, the Neoglacial deposits overlie Kluane deposits, but in other areas, the Neoglacial loess deposit is missing. Borns and Goldthwait (1966) confirm this writer's field observation that Neoglacial loess is still being deposited in the Slims Valley and out into the Shakwak Trench from the terminus of the Kaskawulsh Glacier.

Hypotheses

Considering the glacial history of the region, there are only two likely origins for the soil-sized deposits in the Duke Valley: they were either imported through a process of glacial entrainment (as either indirectly as loess or directly as fine till), or they are the result of local postglacial bedrock weathering. It is hypothesized that these two origins can be distinguished on the basis of mineral assemblage. This is based on the fact that glacial entrainment can pluck materials from a number of widely separated bedrock sources. Transport distances in major icefields are large: commonly of the order of 50km (Holmes, 1952). When materials are transported over distances of this order of magnitude, further weathering takes place, and when they are finally deposited it is preponderantly in the

form of soil-sized particles (Ritter, 1978 and Dreimanis and Vagners, 1971).

During the entrainment process both dispersion and mixing take place. Materials plucked from the glacier floor and sidewalls can rise along shear planes and emerge as supraglacial debris (Ritter, 1978). Conversely materials which collect on the surface of glaciers from subaerial processes can work their way downwards through crevasses and *moulins*. It can therefore be assumed that glacially entrained materials undergo a lengthy and thorough mixing prior to deposition. Based on this assumption, it is postulated that soil-sized materials from the same glacial train will exhibit similar mineral assemblages throughout the zone of deposition regardless of whether this deposition takes the form of fine till or of loess, and even if geological boundaries are crossed during the entrainment process.

In comparison soil-sized materials derived from local bedrock weathering undergo a relatively limited form of mixing. Their movement is largely restricted to colluvial and/or alluvial downslope transportation. Based on this, it is hypothesized that although the mineral assemblage of samples taken from the same mountain slope may display a degree of similarity to one another, they will exhibit a relative degree of dissimilarity to the assemblage of minerals from samples taken from successive slopes down valley with different bedrock exposures. If this is true, then the origin of soil-sized deposits in the Duke Valley can be determined through the degree of similarity of their mineral assemblages. If the assemblages are similar regardless of location throughout the study area, the materials are of glacial origin. If, on the other hand, the assemblages are relatively similar in deposits on the same mountain slope, but relatively dissimilar in deposits on adjacent slopes, then the materials are the product of local bedrock weathering.

The question of glacial entrainment has been examined with respect to origins and englacial mixing. However, if the Duke Valley soil forming materials are in fact of glacial origin, then the equally important question of the means by which these materials were deposited should be addressed. There are two possibilities: either the materials were deposited directly *in situ* as till during glacial ablation, or the material was deposited as loess as a result of aeolian transportation from glacial outwash. Fine till can be distinguished from loess by the particle size distribution characteristics of the materials. It has been long established that during the process of aeolian transport, the wind-blown material is separated from the coarser constituents of the till or outwash and the resulting deposit is fine-skewed. On the other hand, size composition curves of fine till would normally exhibit both coarse and fine tails and display relatively weaker sorting characteristics. It should therefore be possible to determine whether materials in the Duke Valley are loess or fine till deposits on the basis of their particle size distribution characteristics.

Regardless of origin, the materials in the valley have all undergone some form of downslope movement since deposition. This writer has identified visible processes in the field such as: solifluction, landslide, and sheet wash. In addition, there could be some downslope transportation of finer materials in groundwater suspension. The colluvially dominated movements should be distinguishable from the alluvially dominated movements on the basis of particle size distribution characteristics. This hypothesis rests on the proposition that larger particles, because of their smaller specific surface areas, would tend to encounter less frictional resistance to colluvial downslope movement than smaller particles and so result in preferential accumulation of a coarse fraction downslope. On the other hand, in an alluvially dominated transportation environment, the relatively high specific surface area of smaller particles should result in their

preferential accumulation downslope. Based on this, it is postulated that it may be possible to differentiate between colluvially and alluvially dominated downslope processes through comparison of particle size distribution characteristics of samples from sites at differing elevations on the same slope.

Field Methodology

Map 1.3: Location of study areas. Area A contains the materials of unknown origin and Area B contains the known loess deposits.

The two principal investigative methods used in this study were x-ray diffraction analysis to resolve questions relating to mineral assemblage and particle size distribution analysis to resolve questions relating to sorting characteristics. Fundamental to both methods was the requirement to establish standards for comparative purposes. To this end two separate study areas were selected as shown in Map 1.3. Study Area *A* is a 30km stretch of the Duke Valley from which the samples of material of unknown origin were taken, and Study Area *B* is a 20km stretch of the Slims Valley and the southeastern shoreline bluffs of Kluane Lake from which samples of known loess deposits (Borns and Goldthwait, 1966) were taken.

In Study Area *A*, a series of twelve transects was established on the right bank of the Duke River each perpendicular to the river itself. The

Map 1.4: Layout of the Duke Valley transects.

locations of these transects are shown in Map 1.4. The original plan had called for the establishment of transects five kilometers apart on both sides of the river, but this concept was abandoned when it became apparent that solo crossings of the Duke River would be too risky and time consuming. The alternative plan was to establish the 12 transects on the right bank starting 0.7 km downstream from the Neoglacial limit of the river's glacial source and evenly space them every 2.5 km thereafter in order to reduce bias in the site selection process. However, it soon became apparent that even this concept required modification because a number of the proposed transect locations were occupied by tributary creeks and their abandoned channels. This meant that some transect locations had to be adjusted to avoid these areas, and in such cases alternative locations were selected that were situated as closely as possible to the original 2.5 km intervals. A third modification was required when deteriorating weather became an overriding concern. The subsequent necessity to reduce travelling time between transects resulted in the "bunching" of Transects 6 and 7 as well as Transects 8 and 9 as can be seen in Map 1.4.

On each transect four separate sampling sites were selected. The first of these was established at the lowest possible elevation immediately above the floodplain. The uppermost site would then be selected. The criteria used in this case was that the site would be established at the highest elevation at which a layer of unconsolidated material could be found which was at least 20 cm thick and contained less than 50% gravel by volume. Once both the upper and lower sites had been established on the transect line, the upper middle and lower middle intermediate sites were selected at evenly spaced intervals between uppermost and lowermost sites. In this fashion a total of 48 sites were selected on the 12 transects. Each site was identified by both its transect number and the site's position on the transect: e.g., the lowest site on Transect 6 was designated as Site 6L, the lower

middle site on the same transect was designated as Site *6LM*, the upper middle site as *6UM*, and the uppermost site as *6U*. The length of individual transects varied between approximately 1000 and 400 meters. Fifty-gram samples were extracted at the maximum possible depth (to reduce the effects of surface weathering) that could be penetrated without a drill, and which yielded unconsolidated materials containing less than 50% gravel. On the higher sites the constraining factor on sampling depth was normally the presence of bedrock or large clasts. On lower sites the constraint was often the presence of permafrost. Sampling depths varied between 24 centimetres (*2U*, *4U*, and *6U*) and 96 centimetres (*1LM*).

Study Area *B* was used to provide samples from the Neoglacial and Kluane period loess deposits which are known to exist in that area. In the Slims Valley four sites were located in the vicinity of Bullion and Sheep

Map 1.5: Location of known loess deposits in Study Area *B* (SV1 through KL3).

Creeks and are identified by the designations, *SV1* through *SV4* (see Map 1.5). An additional three sites were identified on the southeastern shoreline bluffs overlooking Kluane Lake in the vicinity of Christmas Creek. These are identified by the designations, *KL1* through *KL3*. One fifty-gram sample was extracted from each site. In the case of Neoglacial period loess deposits, samples were taken from the middle of the layer above the White River volcanic ash band. For Kluane period deposits, the samples were taken from the middle of the Slims soil *C* horizon since this parent material is known to be undeveloped Kluane loess (Borns and Goldthwait, 1966).

The loess samples were used in both the x-ray diffraction and particle size distribution analyses. In the former, the loess samples were used to validate the signature comparison concept which was subsequently used to determine the origin of the Duke Valley materials. The diffraction analysis of the loess samples and the subsequent use of this technique on the Duke Valley materials are described in Chapter 2. The loess samples were also used to establish a standard of particle size distribution characteristics for loess materials against which the Duke Valley materials could be compared. The particle size distribution analysis of samples from both study areas is discussed in Chapter 3.

CHAPTER 2

X-RAY DIFFRACTION ANALYSIS

Introduction

In the previous chapter it was postulated that the origins of the dominant soil materials within the Duke Valley could be ascertained by comparing the mineral assemblages of individual soil samples taken from a number of sites within the study area. If a high degree of similarity is found to exist between these assemblages throughout the study area, then loess and/or till deposition is indicated as the dominant material source. If, on the other hand, a high degree of similarity is found only among samples from sites on the same mountain slope, this would suggest that the materials are of local origin, i.e., the byproducts of local bedrock weathering.

This chapter describes the efforts undertaken to test these hypotheses through X-ray diffraction analysis of samples of unknown origin from the 48 Duke Valley sites and seven sites of known loess origin both in the Slims Valley and the Kluane Lake shoreline bluffs directly downwind. Whole sample tests were conducted on the Carleton University's Department of

Earth Sciences x-ray diffraction equipment, and clay fraction tests were conducted on Agriculture Canada's Land Resource Research Centre equipment on behalf of this writer. Apart from during validation testing, no attempt was made to identify individual minerals. Instead, the mineral assemblage trace from each sample was treated as a signature, and the signatures of individual samples were compared to each other by means of an index of signature asymmetry (A-score) which this writer developed as part of this project. The A-score concept was validated by doing a trial analysis of the seven known loess deposits from the Slims Valley and the Kluane Lake shoreline bluffs. These sites were selected for the validation testing because Neoglacial and Kluane loess deposits from this area are known to have nearly identical mineral assemblages (Borns and Goldthwait, 1966).

X-ray Diffraction Signature Comparison

The principles of x-ray diffraction analysis have been discussed in a number of texts including Buerger (1942), Clark (1955), Auleytner (1967), Wormald (1973), Klug and Alexander (1974), Cullity (1978), Brindley and Brown (1980), Whittig and Allardice (1986), and Hardy and Tucker (1988).

Essentially the process used in this case involved bombarding dried soil slurry samples mounted on glass microscope slides with x-rays in a device known as a diffractometer. The pattern of peaks produced by x-ray diffraction of a soil sample can be considered to be the sample's signature which is characteristic of the assemblage of minerals peculiar to that particular sample. Therefore, in theory, one should be able to assess the compositional similarity of two different soil samples simply by measuring the degree of symmetry (or asymmetry) of their diffraction signatures.

In practice, however, this is difficult to achieve since the intensity of a diffraction peak for any specific mineral can be affected by factors as basic as the thickness of sample smear on the individual microscope slide or through chemical and physical alteration of materials in the slide preparation process. To help reduce such sources of error, remedial measures were adopted in the preparation of the sample slides. Firstly, in order to reduce the risk of the finer materials on the slides being shaded from the x-ray beam by coarser particles, the samples were first ground to greater consistency with pestle and mortar. In order to reduce the risk of damage to crystal structures by the heat generated in the grinding process, the samples were first saturated with water. To assist in ensuring constant thickness of materials on all slides, a sheet of newsprint was placed under the slides, and the slurry was applied to each slide in amounts such that the newsprint remained marginally visible through it.

In order to further reduce inconsistencies between samples, it was decided to normalize the signatures of the samples by comparing all peaks within each signature to a single peak common to all of the samples. In the initial assessment of the x-ray diffraction charts, it was found that each chart contained on average approximately thirty recognizable peaks. For the purposes of signature comparison twelve of these peaks were selected. The criteria were that each selected peak should appear in at least 80% of the samples, and the selected peaks had to be fairly evenly spaced throughout the chart in order that the signatures not be biased in favour of certain ranges of lattice spacings at the expense of others. The twelve signature component peaks that were selected as a result of this process are shown in Table 2.1.

It is granted that some of the selected peaks are not entirely independent of the others in all cases. For instance, the 7.0 to 7.2 Å peak

Table 2.1: Selected x-ray diffraction peaks to be used for signature comparison.

Peak (Å)	Possible Mineral Composition
14.0-14.6	chlorite, vermiculite
10.0-10.2	illite
7.00-7.20	kaolinite, vermiculite, chlorite
6.27-6.40	smectite, lepidocrocite
4.98-5.10	illite, goethite
4.60-4.85	magnetite, chlorite, vermiculite
4.26	quartz (diagnostic)
3.50-3.60	vermiculite, chlorite, kaolinite
3.30-3.40	quartz, goethite, lepidocrocite
3.12-3.31	feldspar
2.80-3.00	vermiculite, maghemite, magnetite
1.94-1.98	lepidocrocite, ferrihydrite

may merely be a second order repetition of the 14.0 to 14.6 Å peak, and similarly the same relationship could apply to the 4.98 to 5.10 Å peak with respect to the 10.0 to 10.2 Å peak. It is also not uncommon for two different minerals to share first and second order peaks, e.g., vermiculite and chlorite. In such cases, differences between the two signatures are still detectable in the dissimilar intensity ratios of the two sets of first and second order peaks. On balance it was considered that partial dependence would not appreciably affect overall signature comparison.

It should be noted in Table 2.1 that goethite, lepidocrocite, and ferrihydrite are shown as minerals whose presence could be indicated by the signature. Although this is theoretically possible, their presence would rarely be indicated to any appreciable degree in whole sample analysis because

these minerals commonly occur in fine fractions and would normally be hidden from the x-ray beam by coarser particles. However, it was felt that the possibility of these minerals appearing in whole samples with very small coarse fractions could not be eliminated entirely, and for this reason they were included in the list of possibilities.

From among the twelve selected peaks, one common peak had to be chosen to serve as the normalizing standard against which the other eleven peaks could be compared. A suitable candidate would have to be present in all samples and be as consistent as possible with respect to diffraction intensity (I_o) throughout all samples. In order to make this determination, statistical variances for all 12 diffraction peaks of the 48 Duke Valley samples were computed. These were based on the calculated mean intensities of each of the twelve selected signature peaks. It was found that the diagnostic quartz peak at $4.26\text{\AA}$ was present in all 48 samples and had the lowest variance. This result was not unexpected. The usefulness of quartz as an internal standard to calibrate spacing measurements has long been recognized (Keith, 1955), (Hull, 1976), and (Brindley and Brown, 1980). Having an essentially constant chemical composition and crystal structure, quartz is widely distributed among soil materials and is reputed to be the mineral which presents the least difficulties in quantitative analysis. The $4.26\text{\AA}$ quartz peak was therefore selected as the peak against which all other peaks would be normalized. To this end, the intensity values for all other signature peaks in each sample were converted to ratio values by dividing the intensity value of each peak by the intensity value of the $4.26\text{\AA}$ peak for that particular sample ($I_o/I_{4.26\text{\AA}}$).

The most direct method of diffraction signature comparison between pairs of samples would be to divide the normalized value of each intensity peak of one sample by the normalized intensity value of the corresponding

peak of the second sample, and then to sum these values. The resulting value would in theory reflect the measure of asymmetry of the two signatures. In practice, however, this measure could prove to be misleading. The reasons for this arise out of difficulties inherent in the accurate measurement of peak intensities from the record charts provided by the diffractometer. Due to a relatively low signal to noise ratio, it is very difficult to assess accurately the true position of the signature peaks. In addition the time base produced by some diffractometer models (including the Carleton University machine) is irregularly curved over much of its length making it difficult to determine its exact position under the peaks. These two factors dictate that numerous small errors in intensity measurements are virtually inevitable.

Unfortunately the direct method of signature comparison described above would give equal weighting to both true differences in intensity and these numerous small errors arising from the low signal to noise ratio and the curvature of the time base. This could result in unacceptably distorted signature asymmetry values. It was decided that the simplest and most effective method of reducing this risk to acceptable proportions would be to create an asymmetry index or "A-score" which measures *major* differences only between the intensity values of pairs of signature peaks.

The first step in the process consists of dividing the normalized value of each signature peak in the first sample by the value of its corresponding normalized peak in the second sample as described above. The resulting twelve ratio values of the signatures are then assessed with the aid of a spreadsheet logic programme developed by the author specifically for this purpose. The programme awards two points for each occurrence wherein a signature peak is present in one sample and completely missing (or undetectable) in the second. One point per occurrence is awarded for the

situation wherein the ratio value exceeds 2.0 or is less than 0.5. A zero value is awarded in all other instances. The values thus awarded for each of the twelve pairs of signature peaks are then totalled to give the "A-score" with a range of 24 points for maximum signature asymmetry and zero points for minimal asymmetry.

A-score Validation

In order to validate the A-score concept, samples of loess taken from seven sites (four in the Slim's Valley and three from the bluffs along the southeastern shoreline of Kluane Lake) were subjected to whole sample x-ray diffraction analysis. Six of the sites ranged from 0.2 to 19.0 km distance downwind from the westernmost site (SV2). As discussed in Chapter 1, substantial quantities of both Kluane and Neoglacial loess are found in the area. The two deposits are easy to distinguish in the field since Neoglacial loess invariably contains a horizontal white band of volcanic ash approximately one to two centimetres thick running through the bottom third of the deposit. In the context of this current exercise, however, the visual distinctiveness is largely academic since it has been determined that mineralogically the two deposits are virtually identical (Borns and Goldthwait, 1966). If the A-score concept is valid, then the x-ray diffraction signatures from all samples should give very low A-score readings reflecting this high degree of mineralogical similarity. To conduct this test, the signatures of the six downwind sites were all compared to the signature of SV2, the upwind site, and the resulting ratios were converted to A-scores which are summarized in Table 2.2 below.

If the A-score concept is valid, these six A-scores as a group should

to be significantly lower than the median hypothetical A-score value of 12.5. As can be seen from Table 2.2, the range of A-scores of the loess samples is from zero to three. The mean A-score is only 1.5 which is considerably below the median hypothetical value of 12.5.

Table 2.2: A-scores derived from samples taken from the Slims Valley and along the southeastern shore of Kluane Lake with locations expressed as distances downwind from SV2.

Site	Distance (km)	A-score
SV 1	0.2	1
SV 3	2.0	0
SV 4	2.0	1
KL 1	14.0	3
KL 2	15.0	1
KL 3	19.0	3

To determine the statistical significance of this difference, a χ^2 test was performed using the median hypothetical value as the expected value. In this case, the χ^2 value is 58.68 which indicates that the difference between the observed values and the median hypothetical value is significant at the .001 level. This substantially validates the A-score concept by demonstrating that samples with similar mineral assemblages will reflect this similarity through significantly lower A-scores even when those samples are drawn from widely dispersed sites.

From Table 2.2 it can be seen that although all samples recorded low A-scores, those scores derived from the Kluane Lake samples were slightly higher as a group than those from the Slims Valley samples indicating a slight degree of asymmetry between the mineral assemblages of the two groups of samples. Subsequent particle size distribution analysis of the samples, which is discussed in Chapter 3, indicates that there are significant textural differences between the two groups of samples. The Kluane Lake samples were found to contain larger sand fractions in order of four to five-fold. In such a lacustrine environment, it can be assumed that this sand

enrichment results from the mixing of loess and dune sand material while the deposits were accumulating. That such a large increase in the sand fraction resulted in a relatively minor change in the x-ray diffraction signature indicates that the mineral assemblage of the dune sand and that of the loess is very similar suggesting in turn a common parent material.

Table 2.3: Quartz (3.34Å) to calcite (3.03Å) ratios of the Slims Valley and Kluane Lake deposits.

Site	Quartz/Calcite Ratio
SV1	1.88
SV2	1.96
SV3	1.71
SV4	1.07
KL1	8.13
KL2	3.68
KL3	6.56

This is not at all an unreasonable proposition, since most unconsolidated material in this area was at one time or another glacially entrained debris from the same general area which was subsequently transported by a combination of alluvial and aeolian means to its present locations. The question arises, however, as to how this mineralogical similarity between loess and beach dune could be maintained through

two quite different transportation/weathering regimes. Blanck (1949) conducted a number of complete chemical analyses of both fresh and weathered material in the Arctic and high mountain regions and compared them to similar data under desert conditions. He found that in the colder Arctic and alpine environments, very little chemical weathering took place, and Marshall (1977) confirms these findings.

If chemical weathering is not an important factor in these environments, and if the loess and the dune sand share a common parent material, then one would expect that such abrasion resistant materials as quartz would be more heavily represented in the dune sand than a less hard and more soluble material such as calcite. To investigate whether or not this

had in fact happened in the Slims Valley/Kluane Lake deposits, the quartz to calcite ratios were calculated using the 3.34Å and 3.03Å peaks from the x-ray diffraction data for these samples. The results are shown in Table 2.3 and clearly indicate that there is a considerably higher proportion of quartz in the dune sand-enriched Kluane Lake deposits than there is in the Slims Valley loess deposits. This is entirely consistent with the alpine low chemical weathering scenario, and indicates that the A-score concept is sensitive enough to detect rather subtle differences between deposits which share a common parent material, but have undergone quite different transportation processes.

Whole Sample Analysis

In order to conduct this analysis of the samples from the Duke Valley transects, two separate sets of A-scores were computed. The first set is based on an *intratransect* comparison of samples in which the diffraction signature from one site is compared to the signature from the site immediately below it on the *same* transect.

Table 2.4: Intratransect A-scores derived from samples taken from the Duke Valley. L=lower, LM=lower middle, UM=upper middle, and U=upper.

Transect Position	SLOPE POSITIONS		
	L/LM	LM/UM	UM/U
1	1	7	8
2	0	6	4
3	0	7	1
4	0	0	0
5	2	0	7
6	0	0	8
7	9	0	9
8	5	4	3
9	2	2	4
10	4	4	2
11	3	3	10
12	1	2	7

This produces a set of 36 A-scores which is summarized in Table 2.4. The A-scores derived in this fashion range in value from a low of zero to a high of ten. The mean value is 3.47 and the standard deviation is 3.09.

The second set of A-scores was derived from diffraction signature comparisons conducted on an *intertransect* basis. In this case, the signature of each site is compared to the signature of the adjacent site on the next transect down valley from it, e.g., the signature of the uppermost site on Transect 1 (Site 1U) is compared to the signature of the uppermost site on Transect 2 (Site 2U), etc. This produces a set of 44 A-scores which is summarized in Table 2.5, and ranges in value from zero to seventeen with a mean value of 7.25 and a standard deviation of 4.96.

Table 2.5: Intertransect A-scores derived from samples taken from the Duke Valley (n = 44).

Transects	SLOPE POSITION			
	L	LM	UM	U
1&2	11	11	12	9
2&3	0	0	9	4
3&4	8	11	11	10
4&5	1	4	8	0
5&6	1	6	8	3
6&7	1	8	9	0
7&8	6	5	4	5
8&9	3	5	4	1
9&10	17	14	13	15
10&11	15	14	15	15
11&12	3	3	5	12

The two sets of data (intratranssect and intertransect A-scores) were then examined to determine if the statistical significance of the differences could be assessed by parametric testing. The cumulative distribution for each data set was plotted on probability paper, and it was found that neither distribution was normal. In addition the variance ratio of the two sets at 2.59 indicates that equality of the standard deviations of the background populations cannot be assumed. In short, the data do not satisfy the criteria for parametric testing.

In view of this, the significance of the differences was assessed by means of the non-parametric Mann-Whitney U-test. This test is reported to have nearly 95% of the power efficiency of the widely used parametric Student's t-test (Hammond and McCullagh, 1978). The *U* value for these data is 435.5 which yields a *z* value of 3.45 indicating that the intratranssect A-scores are significantly lower than the intertransect scores at the .0005 level. The conclusion to be drawn from this is that the assemblages of minerals from sites on the same mountain slope have a significantly higher similarity to one another than they do to assemblages from adjacent sites on neighbouring slopes.

Clay Fraction Analysis

The clay fraction analysis was carried out using the Agriculture Canada Land Resource Research Institute diffractometer. This machine eliminates some of the difficulties that are experienced in interpreting the data from the Carleton University diffractometer. The software installed in the former produces a trace with a perfectly flat time base, and the intensities are automatically measured and recorded over each peak. These

two features eliminate potential sources of human measurement error and appreciably speed up the analytical process.

In order to ensure that the data from the clay fraction analysis would be readily comparable to the data from the whole sample analysis, it was hoped that the clay data could be normalized against the 4.26Å quartz peak as was done with the whole sample data. However, the 4.26Å peak was found to be missing in 65% of the clay fraction samples. This is not too surprising. This peak was originally selected as the standard for whole sample analysis in part because quartz is chemically stable under most conditions and very abrasion resistant. However, this stability retards the weathering processes, and because of this, it would be reasonable to expect that the quartz content would tend to be concentrated in the coarser fractions. In addition, although chemically stable in sand and silt-sized fractions, clay-size quartz is less stable in relation to other clay-size minerals. For these reasons, one would anticipate that the 4.26Å peak would appear quite regularly in the whole sample analysis (in which the coarse fraction predominates) while appearing only sporadically in the clay fraction analysis.

A search of the clay fraction data failed to turn up a suitable substitute standard. This meant that the elimination of sample to sample inconsistencies through the normalization process could not be carried out on the clay fraction data. In order to compensate for this, rigorous measures were undertaken to ensure the physical consistency of all the clay samples. For each sample, 30 mg of material, measured to four-decimal place accuracy, was mixed with 1 ml of distilled water measured by syringe. This suspension was slowly applied to the glass microscope slide in order to ensure that the meniscus entirely covered the slide. When dried, the slides were each checked visually with an optical microscope to ensure the highest possible degree of physical consistency.

Aiding the cause of consistency is the much narrower range of particle sizes in the clay fraction. This was evident when slides of the clay samples were compared under microscope with selected whole sample slides. In the latter case, there is considerably less surface uniformity due to protrusions of the coarser sand-sized particles.

Table 2.6: Intratranssect clay fraction A-scores. (n=36)

Transect	Site Position		
	L/LM	LM/UM	UM/U
1	2	5	6
2	0	0	2
3	4	5	0
4	4	2	0
5	2	8	2
6	2	2	2
7	2	0	2
8	2	9	7
9	9	5	9
10	8	4	6
11	12	4	8
12	10	2	0

The resulting A-scores for the clay fraction were calculated on the same basis as those for the whole samples. As with the latter samples, a set of *intratranssect* scores was calculated comparing each site to the site immediately above it on the same transect, then a set of *intertransect* scores was calculated comparing each site to the adjacent site on the neighbouring down valley transect. The set of clay fraction intratranssect A-scores is summarized in Table 2.6.

The intratranssect clay fraction scores are strikingly similar to the corresponding whole sample scores. The mean value for intratranssect clay fraction A-scores is 4.08 compared to 3.47 for the whole sample scores, the range of A-score values is from 0 to 12 for the clay fraction compared to a range of 0 to 10 for the whole samples, and the clay fraction standard deviation is 3.28 compared to 3.09 for the whole samples.

Table 2.7: Intertransect clay fraction A-score. (n = 14)

Transect	Site Position			
	Lower	Lower Middle	Upper Middle	Upper
1&2	6	9	7	7
2&3	2	2	7	4
3&4	6	9	14	13
4&5	5	2	6	1
5&6	2	5	6	7
6&7	2	2	4	5
7&8	9	6	14	10
8&9	7	4	6	11
9&10	15	11	13	12
10&11	9	13	10	12
11&12	7	4	6	4

The set of *intertransect* A-scores derived from the clay fraction analysis is summarized in Table 2.7. This set of scores was also quite similar to that calculated from the corresponding whole sample set. The mean value for the clay fraction set is 7.18 compared to 7.25 for the whole sample set, the range of A-score values is from 1 to 15 for the clay fraction set compared to from 0 to 17 for the whole sample set, and the clay fraction standard

deviation is 3.80 compared to 4.96 for the corresponding whole sample set.

Since the clay fraction data displays the same characteristics which eliminated the possibility of parametric testing of the whole sample data, the non-parametric Mann-Whitney test was once again employed, this time to evaluate the statistical significance of the differences between the clay fraction intratransect A-scores and those derived from the intertransect data set. The resulting *U* value is 432.5, which yields a *z* value of 3.48. This in turn indicates that the A-score values of the intratransect data set are significantly lower than those of the intertransect data at the .0005 probability level as was the case with the whole sample data. In short, results of the clay fraction analysis are strikingly similar to those of the whole sample analysis despite a major difference in the method of determining the A-scores. This not only provides confirmation for the whole sample results, but it also demonstrates that x-ray diffraction signature comparisons are reproducible.

Summary

This chapter describes the comparison of mineral assemblages of soil samples from the Duke Valley through the use of x-ray diffraction analysis. Diffraction signatures of individual samples were compared through the medium of an improvised asymmetry index, the "A-score." The A-score concept was validated through application to Neoglacial loess samples of common mineral composition taken from seven dispersed sites. As predicted, the A-scores obtained were found to be significantly lower in the statistical sense than the hypothetical median score. It was also found that the A-score concept was sensitive enough to identify small changes in

mineral assemblages resulting from dune sand enrichment of the Kluane Lake samples.

Having validated the concept, intratransect A-scores were compared to intertransect values for the samples obtained by whole sample analysis from the 48 sites on the Duke Valley transects. Statistical testing indicates that the intratransect scores are significantly lower than the intertransect scores. This means that mineral assemblages display a higher degree of similarity in samples taken from sites on the same transect than they do in samples taken from adjacent sites on neighbouring transects. This evidence is consistent with the hypothesis that the soil materials on these slopes are dominated by the products of local bedrock weathering. These results were replicated when the clay fraction samples were analyzed.

CHAPTER 3

PARTICLE SIZE DISTRIBUTION

Introduction

A particle size distribution analysis was carried out on soil samples from each of the 48 Duke Valley sites and the 7 loess deposit sites from the Slims Valley and the southeastern shore of Kluane Lake. The objectives of this analysis were twofold: firstly, to confirm the evidence outlined in Chapter 2 concerning the origins of the material, and, secondly, to determine if a sorting process is detectable in the downslope movement of particles in the Duke Valley. Sample preparation and particle size separation were carried out using the facilities of the Land Resource Research Centre, Agriculture Canada. The laboratory procedures adopted were those prescribed in Sheldrick (1984) with modifications as described below.

The separation data were used to construct cumulative particle size distribution curves. Following visual examination of the curves using parameters as defined by Wang (1991), percentile data were extracted for further analysis using Folk and Ward statistical parameters as defined in Folk

(1980) and expanded upon in Lewis (1984) and McManus (1988). To further resolve the question of the role that loess may have played in the accumulation of the deposits in the Duke Valley, the Folk and Ward parameters of the four known loess deposit sites in the Slims Valley were compared to the parameters from the 48 Duke Valley sites.

Laboratory Procedures

The samples were prepared for particle size distribution analysis following the procedures outlined in Sheldrick (1984). Some deviations in procedure were adopted in the latter phases of the process as outlined below. The prescribed procedure was adapted from the United States Soil Survey Method which replaces the time-consuming system of multiple centrifuge washings with a system of ceramic candle filtration. According to Sheldrick, the data determined using this latter system correspond well with the data obtained from material processed by conventional centrifuge washing.

Twenty-gram samples of soil (≤ 2 mm diameter) were placed in 300 mL fleakers. Approximately 10 mL of water was added to moisten the soil sample. Fifty percent hydrogen peroxide was then added, and the samples were allowed to stand until the frothing subsided. The mixture was then heated to 90°C. More hydrogen peroxide was added to the heated mixture until both the colour change and the rate of reaction indicated that most of the organic matter had been destroyed.

The fleakers were then placed in a holding rack and the suspension was processed using the filter candle system. The samples were washed five

times with jets of water strong enough to stir the sample and to filter the suspension through the filter candles. Following the filtration, the samples were oven-dried overnight at 105°C, allowed to cool in a desiccator, and weighed to the nearest milligram. This weight was used as the base weight for calculating the percentages of the various size fractions.

Prior to fraction separation, the samples were dispersed using 10 mL of sodium hexametaphosphate as the dispersing agent. The volume in the fleakers was then made up to 200 mL with distilled water. The stoppers were then shaken end over end at 50-60 rpm overnight. This completed the sample preparation phase.

Each dispersed sample was then poured through a 47 μm sieve into a 1250 mL sedimentation cylinder marked at one litre. The sand retained on the sieve was washed thoroughly with a fine jet of distilled water. The washings were collected in the sedimentation cylinder until the volume of suspension reached about 950 mL. The sieve was then removed, and the final volume was made up to 1000 mL.

The sand retained on the sieve was then transferred to a 100 mL beaker and oven dried at 105°C. The dried sand was transferred to a set of sieves (6 cm diameter) stacked from top to bottom as follows: 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.047 mm, and pan. The sand was poured onto the top sieve, covered, and the sieve set was shaken for ten minutes. Individual sand fractions thus obtained were weighed to four decimal place accuracy.

The Sheldrick (1984) procedure then calls for a determination of the clay content which is subtracted along with the sand fractions from the whole sample weight to determine the silt fraction. Although this approach

adequately satisfies the normal analytical requirements of the Land Resource Research Centre for which these procedures were developed, it does not provide a sufficiently detailed breakdown of the silt fraction for the accurate determination of Folk and Ward statistical parameters. Sheldrick's procedures were therefore modified to permit a separation of the 20 μm , 10 μm , and 5 μm silt fractions as well as a total clay fraction.

The separation of the silt and clay fraction was accomplished through the sedimentation process following the procedures outlined by Sheldrick for separation of the clay fraction only. The theory of particle size separation through sedimentation has been long known and well described in Gee and Bauder (1986). It is based on a relationship developed by Stokes (1851) between the terminal velocity and the diameter of a spherical body falling through a viscous fluid. The application of Stokes' Law to the settlement of soil particles was developed by Krumbein and Pettijohn (1938). The relationship between particle size and settlement time can be determined from the following equation:

$$t = \frac{18 \eta h}{g (\rho_s - \rho_l) \chi^2} \quad \text{Equation 3.1}$$

where t = settlement time, η = fluid viscosity, h = sample depth, g = acceleration due to gravity, ρ_s = particle density, ρ_l = liquid density, and χ = particle diameter.

The above relationship assumes that terminal velocity is attained as soon as settling begins, that settling and resistance are entirely due to fluid viscosity, and that the particles are smooth and spherical. Gibbs *et alia* (1971) have demonstrated that particles < 80 μm in diameter meet the assumptions

concerning terminal velocity as well as settling and resistance. χ is regarded as an "equivalent" rather than an actual diameter.

In order to determine silt and clay-sized fractions, the sedimentation cylinders were placed in a vibration-free room equipped with a Shaw pipet rack. Each sample was stirred with a brass hand stirring rod using an up and down motion for three minutes. The sample fractions were withdrawn at varying depths and predetermined settling times as dictated by Equation 3.1. The settling times ranged from 4.5 minutes for the coarsest silt fraction to 6.5 hours for the clay fraction. Corrections for suspension temperature were made through adjustments to fluid density and viscosity from data provided in Weast (1983).

About one minute before the predetermined settling times, the tip of a 25 ml Lowy pipet was lowered into the suspension to the proper depth using a calibrated Shaw pipet rack. The pipet was filled and then emptied into a tared 100 mL beaker. The pipette was then rinsed with distilled water and emptied again into the same beaker. The beakers were then placed in an oven at 105°C to evaporate the water, cooled in a desiccator containing phosphorus pentoxide as the desiccating agent, and weighed to an accuracy of ± 0.0001 g. The data thus obtained was used to construct the particle size distribution curves upon which the subsequent analysis was based.

Graphical Analysis

There are two recognized approaches to particle size distribution analysis in modern sedimentology both of which are well explained in Krumbein and Pettijohn (1938), Folk (1965, 1980), Friedman and Johnson

(1982), Lewis (1984) and McManus (1988). The earliest of these, the method of moments, is based on the product of the frequency (in terms of weight percentage) and the mid point of each size class in the sample. It has the theoretical advantage of utilizing every single grain in the sample to determine the statistical parameters. However, in order to use this method there must be no open-ended or "pan" fractions, and in this project the clay fractions of the samples are all open-ended. For this reason the alternative graphic method was adopted. In this method a limited number of percentile classes are used to determine the various statistical parameters. The results of the particle size separation for the Duke Valley materials and the loess samples from the Slims Valley/Kluane Lake region were plotted on arithmetic paper. The Slims Valley/Kluane Lake curves are reproduced in Appendix A and the Duke Valley curves in Appendix B. For each sample, particle diameter was plotted against cumulative percent coarser frequency.

In order to use Folk and Ward statistical parameters for the analysis, particle diameters are expressed in phi sizes. The phi scale devised by Krumbein (1934) is a logarithmic transformation of an earlier particle size scale created by Udden and modified by Wentworth in which successive size classes were based on a constant ratio of two. The relationship between metric diameter and phi size is expressed by the equation

$$\phi = -\log_2 d \quad \text{Equation 3.2}$$

where d is the particle diameter in millimetres. The values used to convert metric diameters to phi sizes are given in Table 3.1.

Folk (1965) advocates the use of graphs drawn on probability paper for accurate extraction of statistical parameters. He bases his argument on

Table 3.1: Conversion of metric particle size diameters (mm) to phi sizes.

Metric (mm)	Phi Size
2.0	-1
1.0	0
0.5	+1.0
0.25	+2.0
0.105	+3.25
0.046	+4.40
0.020	+5.60
0.010	+6.63
0.005	+7.6
0.002	+8.95

the observation that " Most sediments tend to approach the 'normal probability curve' in their size distribution the result is a perfectly straight line [and] the 'tails' are straightened out." Normally this would result in more accurate extrapolation and interpolation.

For this present study a set of probability paper graphs was prepared. The Duke Valley samples, however, failed to exhibit the normal distribution

pattern predicted in Folk (1965). The result was that the probability curves were "flattened" rather than "straightened". Although the tails were easier to extrapolate as Folk had suggested, the fact that an appreciable degree of curvature remained combined with the inaccuracies inherent in interpolation of the upper portions of logarithmic scales, made accurate interpolation over the central and upper portions of the curves more difficult. Because of this, the probability graphs were used for extrapolation in the coarse "tail" segments only, while interpolation and extrapolation of the central and upper portions of the curves were carried out on the arithmetic graphs. The probability graphs have not been reproduced in this paper, since the arithmetic graphs convey virtually the same information more effectively.

Visual Examination

A visual examination of the particle size distribution charts in Appendices *A* and *B* reveals that, although the curves for the loess deposits in Appendix *A* are quite smooth and regular, several of the curves for the Duke Valley sites in Appendix *B* are quite irregular and display more than one apparent mode. Polymodal distribution could be indicative of multiple origins. If the materials are indeed the colluvial byproducts of the local weathering of bedrock materials, one could anticipate a polymodal distribution of the particles reflecting the fact that the material has been accumulating as a result of a number of weathering events occurring over time on a number of different local bedrock strata. Single mode distributions, on the other hand, would indicate a more homogeneous source of material such as glacial importation. Convincing evidence of polymodal distribution would therefore support a local weathering hypothesis as opposed to a loess / fine till hypothesis.

Among the 48 curves for the Duke Valley sites, a total of 82 probable polymodal peaks were observed. Of these, fourteen of the apparent modes straddle the boundary between the results obtained by sieving and those obtained by sedimentation (the sand-silt boundary). This raises the possibility that these apparent modes may be due to interface errors which frequently occur when the results obtained by the two methods are combined on the same graph. Nevertheless, this still leaves 68 apparent modes to be accounted for. Although this does represent evidence of polymodalism and, by inference, of multiple origin; it must be pointed out that the modes result from single point deviations. To be more convincing, it would have been preferable that each of these apparent modes had been traced out by a number of consecutive phi size plots instead of just a single plot. However,

in order to assemble that level of evidence, particle size separation by half or even quarter phi sizes would have been necessary. Unfortunately, the available resources limited the separation process to whole phi sizes.

Statistical Parameters

In order to conduct a more detailed examination of the distribution data, the statistical parameters advocated by Folk (1980) were employed. As a measure of average particle size, Folk recommends the use of the Graphic Mean (M_z) as determined from Equation 3.3.

$$M_z = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3} \quad \text{Equation 3.3}$$

The results of this measure correspond very closely to the mean computed by the method of moments method and is preferred over other graph-based measures because it is based on three percentiles rather than one or two.

As a measure of sorting or uniformity, Folk's Inclusive Graphic Standard Deviation (σ_1) was selected. This parameter is determined from Equation 3.4.

$$\sigma_1 = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6} \quad \text{Equation 3.4}$$

This formula covers over 90% of the distribution curve giving the best graph-based measure of sorting.

As a measure of skewness or asymmetry, Folk advocates the use of Inclusive Graphic Skewness (Sk_1) which is determined from Equation 3.5. This formula has an advantage over other graph-based measures of

$$Sk_1 = \frac{\phi_{16} + \phi_{84} - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_5 + \phi_{95} - 2\phi_{50}}{2(\phi_{95} - \phi_5)} \quad \text{Equation 3.5}$$

asymmetry because it utilizes not only the central portions of the distribution curve but the "tails" as well.

As a measure of kurtosis or "peakedness", Folk's Graphic Kurtosis (K_G) was selected and is determined from Equation 3.6.

$$K_G = \frac{\phi_{95} - \phi_5}{2.44(\phi_{75} - \phi_{25})} \quad \text{Equation 3.6}$$

It should be noted, however, that this parameter measures deviation from normal distribution, and, since natural sediments tend to be strongly skewed from normal, this measure has limited usefulness. For this reason Folk recommends that the kurtosis distribution be normalized by means of a transformation, $K_G/(1+K_G)$. The transformed Kurtosis would give a normal distribution a value of 0.5, and would measure most natural sediments at .40 to .65 (Folk, 1980). In view of this, both graphic and transformed kurtosis parameters were calculated for this current study.

Known Loess Deposits

In the previous chapter, mention was made of seven loess deposits located in the Slims Valley and along the southeastern shore of Kluane Lake. These deposits had been identified in the field from descriptions in Borns and Goldthwait (1966), and had been subjected to x-ray diffraction analysis in order to validate the A-score concept. The A-score values obtained indicated a small but detectable difference in the degree of signature asymmetry between the four Slims Valley samples and the three Kluane

Lake samples. This difference was attributed to an increase in the sand fractions of the Kluane Lake samples.

The particle size composition of the loess samples is shown in Table 3.2. The values for the four Slims Valley deposits closely correspond to compositional characteristics of other known loess deposits which have been described as moderately well sorted with nearly 50 % consisting of silt grains between .01 and

Table 3.2: Percentage composition of Kluane Lake and Slims Valley loess deposits.

Site	Sand	Silt	Clay
SV 1	9	88	3
SV 2	9	88	3
SV 3	8	89	3
SV 4	7	89	4
KL 1	53	42	5
KL 2	31	63	7
KL 3	38	54	8

.05mm in diameter (Pesci, 1968), and containing appreciable amounts of clay (5 to 30%) and sand (5 to 10%) according to Ritter (1978). Despite the similarity of their x-ray diffraction signatures to those of the Slims Valley deposits, the Kluane Lake deposits contain considerably larger sand fractions. This may be an indication that these deposits were enriched by beach dune materials which is not an entirely unexpected phenomenon in a lacustrine environment. The fact that the sand enrichment occurred in both the Neoglacial and Kluane period loess deposits suggests that the environmental conditions at Kluane Lake were similar during the later stages of those two events when these depositions are presumed to have occurred.

The statistical parameters for the seven loess deposits are summarized in Table 3.3. The differences between the group of Slims Valley samples and the group of Kluane Lake samples is readily apparent. The Graphic Mean for the Slims Valley group ranges from 5.13 to 5.30 ϕ as opposed to a

coarser range of 4.03 to 5.07 ϕ for the Kluane Lake samples. The differences in sorting are even more dramatic. The Inclusive Graphic Standard Deviation for the Slims Valley deposits range from 0.87 to 0.92 ϕ which equates to "moderately sorted" on Folk's verbal scale and is quite close to the "moderately well sorted" description accorded to other loess deposits by Pesci (1968). On the other hand, sorting deteriorates in the Kluane Lake samples to a range of 1.96 to 3.09 ϕ ("poorly sorted" to "very poorly sorted").

Table 3.3: Statistical parameters of loess deposits in the Slims Valley and along the southeastern shore of Kluane Lake.

Site	Graphic Mean	Inclusive Graphic Standard Deviation	Inclusive Graphic Skewness	Graphic Kurtosis
SV 1	5.30	0.94	0.17	1.78
SV 2	5.17	0.87	0.25	1.55
SV 3	5.17	0.88	0.29	1.59
SV 4	5.13	0.92	0.28	1.78
KL 1	4.30	1.98	0.25	1.21
KL 2	5.07	1.96	0.26	1.71
KL 3	4.50	3.09	-0.07	1.20

The differences between the two groups of samples are also apparent in the other statistical parameters. In terms of skewness, the Slims Valley group ranges from +0.17 to +0.29 ("fine skewed") indicating the presence of a fine tail and the absence of a coarse tail which is typical of aeolian deposits. The samples from KL1 and KL2 fall within this range as well, but the sample from KL3 proved to be "near symmetrical" at -0.07 which is

clearly atypical. The range of Graphic Kurtosis values for the Slims group is 1.78 to 1.55 ("very leptokurtic") indicating better sorting in the "tails" than in the central portion of the curve as expected in aeolian deposits. The range of values for the Kluane Lake group overlap but are slightly lower overall ranging between "very leptokurtic" and "leptokurtic" which is probably due to the influence of the sand enrichment.

The foregoing indicates that there are considerable differences in the statistical distribution parameters between the loess deposits investigated in the Slims Valley and those found along the southeastern shore of Kluane Lake. The Slims Valley group parameters correspond well to the characteristics of other known loess deposits as described by Pesci (1968), Ritter (1978) and Selby (1985) whereas those from the Kluane Lake group

Table 3.4: Summary of graphic means (phi sizes) for the Duke Valley sites. Down valley distance is measured from the Neoglacial terminus.

Transect Number	Down Valley Distance (km)	SITE POSITION			
		Lower	Lower Middle	Upper Middle	Upper
1	0.7	5.47	5.53	5.37	4.17
2	3.2	6.10	6.10	6.53	6.90
3	5.7	4.97	6.17	5.67	5.13
4	8.6	5.37	5.60	6.87	6.20
5	11.1	4.17	7.43	3.33	3.03
6	12.3	4.83	5.00	5.17	5.23
7	13.2	5.13	4.10	3.80	4.83
8	15.7	6.30	4.60	4.93	5.00
9	16.7	5.83	4.40	4.50	4.03
10	23.4	4.33	1.00	1.90	0.17
11	25.4	3.23	5.63	3.63	3.27
12	28.2	4.40	5.00	3.37	5.93

are atypical as a result of sand enrichment. Both Kluane and Neoglacial loess deposits are known to exist in the Donjek Valley (Denton, 1965) as well. This means that the Duke Valley study area lies between two known areas of Kluane and Neoglacial loess deposition. For these reasons the parameter ranges as defined by the Slims Valley group of samples will serve as an appropriate standard against which the materials from the Duke Valley study area can be assessed. The standard parameter ranges to be used are 5.13 to 5.30 ϕ for the Graphic Mean, 0.87 to 0.92 ϕ for Inclusive Graphic Standard Deviation, +0.17 to +0.29 for Inclusive Graphic Skewness, 1.55 to 1.78 for Graphic Kurtosis and 0.61 to 0.64 for Transformed Kurtosis.

Duke Valley Materials

The graphic mean parameters for the 48 Duke Valley sites are summarized in Table 3.4. Only 4 sites fit within the standard range for this parameter as defined above, 24 of the sites had coarser means and the remaining 20 were finer. The average mean at 4.78 ϕ was coarser than the standard range.

The sorting characteristics of the Duke Valley samples as expressed in terms of inclusive graphic standard deviation are given in Table 3.5. On Folk's verbal scale the samples range from "poorly sorted" to "very poorly sorted", a range of values which is characteristic of flood plain silts and clays (Folk, 1980). It is of interest to note that *none* of the Duke Valley samples fall within the Slims Valley loess standards for sorting.

Table 3.5: Summary of inclusive graphic standard deviation parameters (phi sizes) for the Duke Valley sites.

Transect Number	SITE POSITION			
	Lower	Lower Middle	Upper Middle	Upper
1	1.40	2.33	2.50	3.11
2	2.30	2.52	2.29	1.62
3	2.58	2.36	2.93	3.36
4	2.13	2.72	1.79	3.09
5	3.66	1.90	3.41	3.60
6	3.53	3.57	3.68	3.67
7	2.74	3.06	3.19	3.16
8	2.98	3.53	3.69	2.94
9	3.35	3.51	3.86	3.87
10	3.85	1.97	2.96	1.56
11	3.17	3.28	3.53	3.56
12	2.61	3.38	2.57	2.02

Table 3.6: Summary of inclusive graphic skewness values for the Duke Valley sites (negative values in parentheses).

Transect Number	SITE POSITION			
	Lower	Lower Middle	Upper Middle	Upper
1	0.07	0.03	0.07	(0.36)
2	(0.16)	(0.23)	(0.18)	0.07
3	(0.09)	(0.16)	(0.39)	(0.38)
4	(0.49)	(0.31)	(0.24)	(0.43)
5	0.06	(0.36)	0.35	0.37
6	(0.16)	(0.17)	(0.20)	(0.22)
7	(0.16)	0.12	0.02	(0.12)
8	(0.19)	(0.05)	(0.18)	0.20
9	(0.12)	(0.03)	0.06	0.06
10	0.07	0.49	0.55	0.44
11	0.30	0.11	0.23	0.28
12	0.07	(0.04)	0.37	0.21

A summary of the inclusive graphic skewness values for the Duke Valley sites is given in Table 3.6. These values cover a range from "strongly fine -skewed" to "strongly coarse-skewed," but despite this broad range only 4 of the 48 sites matched the standard skewness values for Slims Valley loess.

A similarly broad range was observed in the graphic kurtosis values

Table 3.7: Summary of graphic kurtosis values for the Duke Valley sites.

Transect Number	SITE POSITION			
	Lower	Lower Middle	Upper Middle	Upper
1	1.98	1.75	1.26	0.81
2	1.43	1.40	1.57	1.16
3	1.29	1.60	1.36	1.09
4	1.57	1.14	1.97	1.14
5	0.63	1.29	0.67	0.67
6	0.80	0.80	0.81	0.77
7	1.51	0.81	0.76	0.89
8	1.07	0.87	0.79	6.83
9	0.83	0.80	0.72	0.71
10	1.11	1.26	1.22	1.78
11	0.91	0.99	0.80	0.77
12	0.95	1.02	1.20	0.87

(Table 3.7) ranging from "platykurtic" to "very leptokurtic" on the verbal scale. Once again, only 4 of the 48 sites matched the standard values for Slims Valley loess. Folk (1980) states that the normal spread for most sediments is around 0.8 to 1.40. The spread for the Duke Valley samples is somewhat broader than this.

Taken together the parameters reveal that the Duke Valley deposits tend towards coarseness, are poorly sorted and exhibit a broad range

skewness and kurtosis. Despite the broad range of characteristics, very few samples matched any of the parameter standards for Neoglacial and Kluane loess established in the Slims Valley, and *none* of samples matched all of the standards. In fact, none of the samples would even match standards relaxed to include the parameter values of the three sand-enriched Kluane Lake loess deposits. If loess is a component of the Duke valley materials, its presence was not revealed in this analysis.

As indicated in the foregoing, comparison of the Duke Valley samples to loess standards derived from the Slims Valley samples failed to reveal the presence of a loess component among the Duke Valley samples. In order to pursue the investigation further, it was decided to examine the Duke Valley samples as a group to determine if any trends exist in the parameter data which might indicate an otherwise hidden loess component. Ruhe (1969) and others maintain that the particle size of loess deposits decreases with demonstrable regularity downwind. Although Ruhe is thinking in terms of hundreds of kilometers, and the Duke Valley study area is only thirty kilometers in length, it was, nevertheless, considered worthwhile to do a study to determine if statistically significant correlations exist between the various parameters and down valley site distance even over such a short distance. To do this, individual parameters values were arranged according to the down valley distance of their respective sites as measured from the Neoglacial terminus.

It was also decided to do a further series of correlation tests to determine what if any relationship existed between the particle size distribution characteristics of a site and those of other sites at varying elevations. The object of this series of tests was to determine if any detectable sorting occurs as the materials migrate downslope. Such evidence could potentially provide an indication as to whether the move was

principally colluvial or alluvial (sheetwash) in nature. In order to accomplish this, individual parameters were arranged according to the elevation of their sites above local flood plain.

In order to get the most reliable results the parametric Product Moment Correlation Test was employed. All data meet the criteria for parametric testing except the graphic kurtosis data which, as indicated earlier, tend to be strongly skewed in natural sediments. To overcome this limitation, transformed kurtosis data were used which do approximate normal distribution. A significance level of $p = 0.001$ was selected for a two-tailed test.

In the first test the correlation between the graphic mean parameter and down valley distance was examined and indicated that a significant ($r = -0.51$ and $t = -4.03$) negative correlation exists. It can therefore be established that the coarseness increases with distance throughout the study area. A possible cause of such a phenomenon would be that a very limited supply of loess exists which has been deposited more heavily on the up valley slopes, but which has "tailed off" down valley. In order for this to have happened, the down valley winds would have to have been extraordinarily light, or the loess particles would have to have been extraordinarily heavy (approaching sand size), or both, but no evidence was been found to support such hypotheses.

In the second test the correlation between the graphic mean parameter and elevation above flood plain was examined. The result was a very weak ($r = -0.12$ and $t = -0.82$) negative correlation which would not have been significant even at the 0.1 level.

The correlation between inclusive graphic standard deviation and

down valley distance was tested next. A weak positive correlation ($r = +0.44$ and $t = +3.32$) was found to exist which was significant only at the 0.01 level. A test of this parameter with respect to elevation above flood plain yielded an even weaker positive correlation ($r = 0.24$ and $t = 1.69$) which was significant only at the 0.1 level.

However, a significant positive correlation ($r = +0.57$ and $t = +4.76$) was found to exist between inclusive graphic skewness and down valley distance. This would indicate that the samples became progressively fine-skewed with distance. Within a loess deposition context this would suggest that loess, a characteristically fine-skewed material, is (was) being deposited in progressively larger amounts down valley. This could result from the river depositing progressively larger amounts of fine material on its floodplain as it loses transport competence. The material thus deposited would then be available for aeolian transport and subsequent re-deposition as loess on the valley slopes.

The controlling mechanism for such a process would be river channel width. The Duke River follows essentially a single channel course through the upper portion of the study area which contains the first five transects. From that point on, the channel progressively widens, and the river adopts a braided channel configuration in which the discharge velocity (and transport competence) drops appreciably leaving behind progressively greater amounts of material available for aeolian transportation down valley. However, it must be noted that this correlation between skewness and distance runs counter to the only other significant correlation to be found in this study -- the first correlation between graphic mean and distance which suggested that the deposits become progressively *coarser* down valley.

The remaining correlation tests: inclusive graphic skewness *versus*

elevation above floodplain ($r=0.10$ and $t=0.70$), transformed kurtosis *versus* down valley distance ($r=-0.26$ and $t=-1.83$), and transformed kurtosis *versus* elevation above floodplain ($r=-0.14$ and $t=-0.98$), all failed to yield significant results. The fact that significant correlations could not be established between elevation above flood plain and any of the parameters indicates that any sorting which might be accomplished through the migration of materials downslope is too small to be detected by these tests.

Summary

In this chapter the particle size distribution analysis has been discussed. This analysis was conducted on samples from the 48 Duke Valley sites as well as from loess deposits at seven sites in the Slims Valley and along the southeastern shore of Kluane Lake. The particle size distribution curves were examined visually, and data were extracted to determine Folk and Ward statistical parameters for mean size, sorting, skewness and kurtosis. The Duke Valley parameters were compared to a standard range for Kluane and Neoglacial loess as determined from the four Slims Valley loess samples. Product moment correlation tests were also conducted on the Duke Valley parameters to determine if significant correlations existed between the parameters and two other variables, down valley distance and elevation above local flood plain.

The analysis yielded a number of results including some evidence of polymodalism in the Duke Valley materials but none in the samples from the known loess deposits. The four loess samples from the Slims Valley were found to conform closely to the accepted standards for loess materials. The three Kluane Lake samples however display atypical enrichment of the sand

fraction. The Duke Valley samples were on average coarser and much more poorly sorted than the standard loess. The correlations between the Duke Valley parameters and down valley distance yielded ambiguous results. The correlations between these parameters and elevation of the site above local flood plain suggest that detectable amounts of sorting do not occur among the Duke Valley materials during downslope migration.

CHAPTER 4

CONCLUSIONS

The objectives of this study were to determine the dominant source of the soil-sized particles on the slopes of the Duke Valley and the mode of their subsequent downslope migration. In Chapter 1, it was postulated that the question of origins could be resolved through x-ray diffraction and particle size distribution analyses of soil samples taken from sites at various elevations along a series of transect lines which were established perpendicular to the course of the Duke River. It was further postulated that questions related to the downslope migration of these materials could be resolved through an examination of their sorting characteristics as revealed through the particle size distribution analysis. The results of the x-ray diffraction analysis were reported in Chapter 2, and those of the particle size distribution analysis in Chapter 3. This chapter will discuss the conclusions which have been reached as a result of these investigations, and will end with a statement concerning the effectiveness of x-ray diffraction signature comparison as one of the principal investigative tools in this study.

Origins

The investigation of origins started with the premise that there were only two likely origins for the soil-sized materials in the Duke Valley: that

they were glacially entrained materials that were imported into the valley either in the form of loess and/or as fine till, or that these materials are the products of local bedrock weathering. It was thought that the question of loess *versus* fine till could be resolved through particle size distribution analysis, and that the broader question of glacial importation *versus* local bedrock weathering could be addressed by a combination of particle size distribution and x-ray diffraction analyses.

Although the Duke Valley lies between two major neighbours both of which contain widespread loess deposits, and contrary to the visual evidence that loess is being created in the lower Duke Valley even to this day, the bulk of the evidence collected in this study indicates that loess is not a major component of the soil-sized particles currently occupying the slopes of the Duke Valley. The most convincing evidence of this is the fact that none of Duke Valley samples matched the standards established for loess through particle size distribution analysis of known Slims Valley loess deposits. In fact, the Duke Valley samples do not even match the more relaxed standards which include the sand-enriched loess samples from the Kluane Lake shoreline bluffs. Unlike the known loess deposits, the Duke Valley materials have sorting characteristics ranging from poor to very poor, a coarser average graphic mean particle size, and a broader range of graphic kurtosis values.

In addition, evidence that could be taken to indicate that loess might be a component is both weak and unconvincing. It consists of a single positive correlation between graphic skewness of the individual samples and downvalley distance indicating the materials become progressively fine-skewed (more loess-like) downvalley, but this is contradicted by a negative correlation between graphic mean particle size and downvalley distance which would suggest that the materials become progressively less loess-like

down valley.

If the dominant material is not loess, then it must be either fine till or the product of local bedrock weathering. One of the hypotheses upon which this study is based is that glacially entrained materials would undergo a thorough mixing process during glacial transport, and hence deposits of this material would have similar mineral assemblages regardless of their location within the area of deposition. On the other hand, although local weathering products would be expected to show a high degree of similarity in their mineral assemblages and consequently a low degree of diffraction signature asymmetry among sites on the same mountain slope, they would have a significantly lesser degree of similarity (higher degree of signature asymmetry) when compared to adjacent sites on neighbouring slopes. The data from the whole sample x-ray diffraction tests indicate that diffraction signatures are significantly less asymmetrical (mean A-scores of 3.37 *vice* 7.25) among samples taken from sites on the same mountain slope than among samples from adjacent sites on neighbouring slopes. The data from the clay fraction tests yielded similar results (mean A-scores of 4.08 *vice* 7.18). These data are entirely consistent with the proposition that the dominant soil-sized material in this valley is the product of local bedrock weathering.

Additional support for this proposition was found in the polymodal nature of the particle size distribution curves. A total of 68 modes were counted in the 48 Duke Valley distribution curves. Polymodalism in this case is most likely indicative of local accumulations of material as a result of a number of weathering events occurring over time on the same mountain slope but in different local bedrock strata. Normally this evidence would not be too convincing since the modes result from single point deviations. Rather than being indicative of polymodal distribution, such single point

deviations could conceivably have resulted from the use of whole phi size particle separation instead of separation by half or quarter phi sizes. However, the case for the proposition that they do indicate polymodal distribution is shored up by the fact that not a single case of similar single point deviation occurs in seven known loess samples despite the fact that identical whole phi size separation procedures were employed in both cases. Because of this it is concluded that polymodalism does exist in the distribution curves for the Duke Valley samples, and that this supports the proposition that the composition of these materials is dominated by the weathering products of the local bedrock.

The reason why glacially entrained materials have not been detected in the Duke Valley samples may be due to any or all of the following reasons: the configuration and orientation of the valley may inhibit aeolian transportation of the finer fraction of the glacially imported materials, the relatively steep gradient of the valley floor throughout the study area may inhibit the accumulation of soil-sized ablation and outwash materials, the materials may have been buried by debris from subsequent local weathering, and thorough mixing and weathering of materials during glacial transport may not have occurred in this instance. With respect to the first of these explanations, a basic map study reveals that the configuration of the Duke Valley is such that it is much more confined than either of its major neighbours, the Slims or the Donjek Valley, and is oriented at right angles to the prevailing wind. These two factors working together could inhibit aeolian transport to a degree. However, despite the confined configuration, loess clouds of considerable thickness have been observed moving down the valley, and the Donjek Valley, which has roughly the same orientation, does contain widespread loess deposits. Therefore, although valley configuration and orientation could be factors in inhibiting the development of loess deposits, it is unlikely to be the sole reason for the absence of detectable

loess deposits.

It was noted earlier that the relatively steep gradient of the valley floor might explain the absence of detectable quantities of outwash materials. The gradient within the study area was measured at 10.1 m/km which is much more severe than the 1.0 m/km gradient found in the Slims Valley. It could therefore be argued that this would provide the Duke River with a much higher transport energy source and hence greater transport competence than the Slims River. If the energy level were high enough, the Duke could theoretically flush its sediment load straight through the valley without allowing detectable amounts of the finer outwash materials which enter the valley to accumulate. However, the upper Donjek Valley gradient at 8.7 m/km is almost as severe as that of the Duke, and yet the Donjek River has permitted its outwash materials to settle out and form the basis for subsequent production of loess deposits within its bounds. Therefore, although the gradient of the valley floor could be a contributing factor, it may not be the sole reason for the absence of identifiable fine outwash products within the Duke Valley study area.

Glacially entrained material could have been deposited within the valley and then have been buried under local weathering debris. The Duke Valley has a very active physical weathering regime, and debris cones abound. In fact next to the solifluction lobe, the debris cone is the most prevalent landform throughout much of the valley. Although this debris is widespread, it is by no means uniformly spread. In many places, bedrock outcroppings appear, and in other places both the river and its tributary creeks have cut down to bedrock. In such locations the more deeply buried materials are exposed, and none of these materials appears to be noticeably different in texture from surface materials.

The last alternative explanation is that the flow of material from the main icefield into the Duke Valley was blocked both during the Neoglacial and during the Kluane Glacial which preceded it. If such long range entrainment did not take place, the thorough mixing upon which the original hypothesis was predicated could not have taken place, and from the shorter entrainment, one would anticipate less abrasion of individual particles. In general, the resulting debris would be more local in origin and, as a consequence of this, less homogeneous in terms of mineral assemblage. The debris would also likely be coarser as a result of less abrasion.

Approximately 12 km southwest of the current glacial limit of the source of the Duke River lies a ridge which runs at right angles to the direction of ice flow. This ridge, which appears to be an extension of the southern flank of the Donjek Range, is approximately 11 km long and rises roughly 1500 feet (457 m) above the current ice surface to peak elevations in the order of 10,000 feet (3048 m). It is currently a complete barrier to the northeasterly flow of ice into the Duke Valley from all points west of the Donjek Range, and considering its height above the current ice surface and the limited nature of Neoglacial advance, it can be safely assumed that it was also a complete barrier even during the Neoglacial maximum.

Approximately 18 km further to the southwest lies a second ridge running parallel to the first. The second ridge is approximately 5 km in length, reaches elevations of 10,500 feet (3200 m), and rises roughly 2500 feet (762 m) above the current local ice surface. This ridge is currently a complete barrier to the northeasterly flow of ice into the Duke Valley from the main icefield. The ice is currently deflected by this ridge northwards to join the Kluane Glacier, source of the Donjek River, and southwards where it joins the Kaskawulsh Glacier, source of the Slims River. It can be safely assumed that this ridge was also a complete barrier to the flow of material

from the main icefield into the Duke Valley throughout the Neoglacial.

The question arises as to what extent these ridges were barriers to ice flow (and, hence, to long range entrainment) during the Kluane Glacial. Unfortunately, lack of resources prevented a full investigation of glacial scouring on both ridges. In July, 1990, this writer did a brief low-level fixed-wing reconnaissance of the area. The visual evidence suggested that at least two of the peaks on the westernmost ridge, and perhaps one of the peaks on the other ridge may have protruded above the ice surface as *nunataks*, but the intervening saddles were snow covered and, hence, it could not be determined if they had been overridden during the Kluane. A subsequent examination of the contours of the slopes leading up to the saddles, however, revealed that they are quite steep and may even exceed 30 degrees in places which suggests that they may not have been overridden in the recent geological past.

If this is true, then the Kluane period valley glacier which flowed down the Duke Valley would have been fed entirely by local snow accumulation. The resulting ice would have been contributed to the main valley glacier by a series of cirque glaciers located along the length of the valley in the same manner as the modern tributary creeks contribute to the present Duke River. The entrained materials that the glacier would be carrying under these circumstances would be coarser and relatively unmixed compared to materials which had undergone long range entrainment. Much of the relatively small fine fraction could have been flushed straight through the study area due to the high transport competence of the fluvial action. The limited outwash materials which remained within the area could produce loess, but in insufficient quantities to provide identifiable accumulations. Any remnants of materials originally entrained in the tributary cirque glaciers that were subsequently stranded on the valley slopes would blend in with

postglacial weathering products and could be mineralogically indistinguishable from them.

On balance, the blockage of long range entrainment by the two southwesterly ridges appears to be the most credible primary reason for the lack of detectable accumulations of fine glacially entrained materials in the Duke Valley study area. This explanation has a distinct advantage over the others in that it is the one explanation which describes a set of circumstances which is unique to the Duke Valley, i.e., both the Slims and the Donjek Valleys are known to have received influxes of long range glacially entrained materials, but it would appear that the Duke Valley has not. This argument would be even more convincing if it could be determined conclusively that the flow from the main icefield was blocked during the Kluane Glacial. A detailed ground reconnaissance of the barrier ridges could have resolved the question, but a lack of resources prevented this from being done during this study.

Downslope Movement

The attempt to determine the dominant mode of downslope movement relied on particle size distribution analysis of the 48 Duke Valley samples. This was based on the hypothesis that an alluvial transport mode such as sheetwash would result in preferential accumulation of the fine fraction downslope, whereas a colluvial transport mode would result in the preferential downslope accumulation of the coarse fraction. The theoretical premise for this was that smaller particles with their greater specific surface areas would derive more hydrodynamic lift and hence be preferentially transported in a predominantly alluvial environment, whereas larger particles

with correspondingly low specific surface areas would experience less frictional resistance to downslope movement in a predominantly colluvial environment and would be preferentially transported as a consequence. In other words, it was anticipated that the predominant mode of transport could be identified through analysis of the sorting characteristics of the materials as revealed through particle size distribution analysis.

The results of the analytical data are ambiguous at best. During visual examination of the distribution curves, it was noted that there was an apparent tendency for the coarse fraction to decrease progressively in downslope sites and for the fine fraction to correspondingly increase. This phenomenon was observed in eight of the twelve transects. However, subsequent statistical testing indicated that the possibility of random distribution could not be eliminated even at the 0.1 significance level. To pursue the question further, correlations between Folk's statistical parameters and elevations above local floodplain were investigated. No statistically significant correlations were uncovered. The conclusion to be drawn from all this is that any sorting action which may have occurred during the migration of these materials downslope is too small to be detected by these tests in the manner in which they were conducted.

The solution to the problem could well lie in more accurate research methods. In this study particle sizes were separated on the basis of whole phi sizes. Analysis on the basis of half size or even quarter size separations might yield less ambiguous results. Increased sampling might also help as could detailed examination of distributions within individual solifluction lobes.

The problem could also lie within the theoretical premise upon which this analysis was based. The visual evidence in the field suggested that the solifluction lobe was the dominant landform, and because of this it was

anticipated that solifluction might well be the dominant transport mode. It was assumed that since solifluction is basically a colluvial process, the coarse fraction would be preferentially transported. However, this may not be true. Solifluction occurs in saturated soils where frictional drag is minimized. Under such circumstances, normal colluvial sorting may not occur to any detectable degree, if indeed it occurs at all. A subsequent study employing the analytical methods outlined in the paragraph above might well confirm this hypothesis.

Diffraction Signature Comparison

The final aspect of this study which should be addressed in this concluding section is the assessment of the usefulness of x-ray diffraction signature comparison as an investigative tool in problems of this nature. The validation test for this technique consisted of a series of signature comparisons between samples known to share similar mineral assemblages. The comparisons were done on seven samples taken from known loess deposits in the same general region. The mean A-score for the four Slims Valley samples was 0.7 and mean A-score for the comparisons of Site SV2 to the three Kluane Lake samples was 2.3. Both mean values are significantly lower than the median hypothetical score of 12.5 and indicate that all seven samples are of similar mineral composition. This was the anticipated result.

The surprise result was the small but obvious difference between the Slims Valley scores and those based on the comparison between SV2 and the Kluane Lake samples. A plausible explanation was provided in subsequent particle size distribution analysis when it was discovered that the Kluane

Lake samples contained appreciably enriched sand size fractions. Since the additional sand would in all likelihood have come from the same source as the fine fractions, i.e., reworked fractions of the long range glacial entrainment products from the main ice sheet, it could be anticipated that the resulting A-scores would reflect a measure of mineralogical similarity, while at the same time one would expect the scores to also reflect modest differences in composition due to differential physical weathering of minerals of varying degrees of abrasion resistance. The anticipated result of such factors would be that the coarser fraction would contain a higher proportion of the more abrasion resistant minerals. Subsequent analysis of quartz/calcite ratios indicated that differential physical weathering was occurring in a pattern expected of a cold, semi-arid environment. In short, the A-scores obtained from the validation test appear to be entirely consistent with both the known facts and the fundamental assumptions upon which the test was constructed.

While the validation testing suggests that the technique produces predictable results, its subsequent application to the Duke Valley samples indicated that it is also capable of rendering reproducible results. Two sets of diffraction signature comparisons were produced, one based on whole sample diffraction, and the other on clay fraction diffraction. As described in Chapter 3, the two sets of results were remarkably similar despite some basic differences in the calculation processes. This suggests that the technique may even be capable of offering a measure of independent verification of its own results.

The foregoing suggests that the technique appears to be both predictable and independently verifiable. Experience has shown that it is also capable of efficiently providing considerable information with a minimal expenditure of effort in the laboratory. Including clay separation (five days),

the particle size distribution analysis for this study took six weeks to complete. Including sample preparation but excluding clay separation, the diffraction signature comparisons using two diffractometers took only three days each for the whole sample and the clay fraction sets. Despite this, the signature comparisons provided as much valuable information for this study as did the particle size distribution analysis. This does not mean that the one is a substitute for the other, since they produce different types of information and are therefore complementary to one another, but it does indicate that the signature comparison technique is potentially a powerful and efficient tool in studies such as this.

However, before a more complete endorsement of the technique can be given, the limitations of this current evaluation must be considered. The first of these is that the validation test was done on a seven-sample set which means that the significance of the outcome cannot be statistically verified at an acceptable level of confidence. The second is that the technique has been employed in a rather restrictive weathering environment in which virtually all weathering has been of the physical variety. Before this technique can be accorded anything more than tentative acceptance, these verification deficiencies will have to be addressed.

REFERENCES

- Arnold, R.W. (1965) Multiple working hypothesis in soil genesis. *Soil Sci. Soc. of Am. Proc.* **29**, 717-724.
- Auleytner, J. (1967) *X-ray Methods in the Study of Defects in Single Crystals*. Pergamon Press, Oxford.
- Beal, M. Alan and Shepard, Francis P. (1956) A use of roundness to determine depositional environments. *J. Sedim. Petrol.* **26**, 49-60.
- Blanck, E. (1949) *Einführung in die genetische Bodenlehre*. Vandenhoeck und Ruprecht, Göttingen.
- Borns, Harold W. Jr. and Goldthwait, Richard P. (1966) Late-Pleistocene fluctuations of Kaskawulsh Glacier, southwestern Yukon Territory, Canada. *Am. J. Sci.* **264**, 600-619.
- Bostock, H.S. (1969) Kluane Lake, Yukon Territory, its drainage and allied problems. *Geological Survey Paper 69-28*. Geological Survey of Canada, Ottawa.
- Brindley, G.W. and Brown, G. (eds.). (1980) *Crystal Structures of Clay Minerals and Their X-ray Identification: Mineralogical Society Monograph No.5*. Mineralogical Society, London.
- Buerger, M.J. (1942) *X-ray Crystallography*. John Wiley and Sons Inc., New York.
- Clark, G.L. (1955) *Applied X-rays*. McGraw-Hill Book Co. Inc., New York.
- Crossley, D.J. and Clarke, G.K.C. (1972) Thermal drilling and deep-ice temperatures measurements on the Rusty Glacier. In: (eds.)

- Bushnell, V.C. and Ragle, R.H. *Icefield Ranges Research Project Scientific Results*. The Arctic Institute of North America, Montreal, 3, 103-116.
- Cullity, B.D. (1978) *Elements of X-ray Diffraction*. Addison-Wesley Publishing Co., Reading.
- Denton, G.H. (1965) *Late Pleistocene Glacial Chronology, Northeastern St. Elias Mountains*. Ph.D. Dissertation, Yale University.
- Denton, G.H. and Stuiver, M. (1967) Late Pleistocene glacial stratigraphy and chronology, northeastern St. Elias Mountains, Yukon Territory, Canada. *Geological Society of America Bulletin*, 78, 485-510.
- Denton, G.H. and Karlén, W. (1973) Holocene climatic variations - their pattern and possible cause. *Quaternary Research*, 3, 155-205.
- Denton, G.H. and Stuiver, M. (1966) Neoglacial chronology, northeastern St. Elias Mountains, Canada. *Am. J. Sci.* 261, 577-599.
- Douglas, George W. and Knapik, L.J. (1974) *Montane Soil Characteristics in Kluane National Park*. Canadian Wildlife Service, Ottawa.
- Drake, L.D. (1971) Evidence of ablation and basal till in east-central New Hampshire. In: (ed.) Goldthwait, R.P. *Till: A Symposium*. Ohio State University Press, Columbus.
- Dreimanis, A., and Vagners, U.J. (1971) Bimodal distribution of rock and mineral fragments in basal till. In: (ed.) Goldthwait, R.P. *Till: A Symposium*. Ohio State University Press, Columbus.
- Folk, Robert L. (1980) 8th Edition. *Petrology of Sedimentary Rocks*. Hemphill Publishing Company, Austin.
- Folk, Robert L. (1965) *Petrology of Sedimentary Rocks*. Hemphill Publishing Company, Austin.
- Fremlin, G. (ed.) (1974) 4th ed. (Revised). *The National Atlas of Canada*. The Macmillan Co. of Canada Ltd., Ottawa.
- Friedman, G.M. and Johnson, K.G. (1982) *Exercises in Sedimentology*. John Wiley and Sons Inc., New York.

- Gee, G.W. and Bauder J.W. (1986) Particle size analysis. In: *Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods*. American Society of Agronomy - Soil Science Society of America, Madison, 383-411.
- Gibbs, R.J., Mathews, M.D., and Link, D.A. (1971) The relationship between sphere size and settling velocity, *J. Sed. Petrol.* **41**, 7-18.
- Gross, D.L., and Moran, S.R. (1971) Grain-size and mineralogical gradations within tills of the Allegheny Plateau. In: (ed.) Goldthwait, R.P. *Till: A Symposium*. Ohio State University press, Columbus.
- Hammond, R. and McCullagh, P.S. (1978) *Quantitative Techniques in Geography: an Introduction*. Oxford University Press, Oxford.
- Hardy, Ron and Tucker, Maurice. (1988) X-ray powder diffraction of sediments. In: Tucker, Maurice (ed.). *Techniques in Sedimentology*. Blackwell Scientific Publications, Oxford, 191-228.
- Holmes, C.D. (1952) Drift dispersion in west-central New York. *Geol. Soc. Amer. Bull.* **63**, 993-1010.
- Hughes, O.L. , Rampton, V.N., and Rutter, N.W. (1972) Quaternary geology and geomorphology, southern and central Yukon. *24th Internat. Geol. Congress: Guidebook A11*. Montreal.
- Hull, D.H. (1976) Quartz as an internal standard for identification of minerals. *J. Applied Crystallog.* **9**.
- Jackson, M.L. and Schuman, G.D. (1953) Chemical weathering of soils. *Advances in Agronomy*, **5**, 219-318.
- Johnson, P.G. (1975) Environmental controls on geomorphic processes, Grizzly Creek, south-west Yukon Territory. *Research Note No.6*. Ottawa University, Ottawa.
- Keith, H.D. (1955) Lattice spacings in clear crystalline quartz and their variability. *Am. Miner.* **40**.
- Klein, Cornelius and Hulbut, Cornelius S. Jr. (1977) *Manual of Mineralogy*. John Wiley and Sons Inc., New York.
- Klug, H.P. and Alexander, L.E. (1974) *X-ray Diffraction Procedures for Polycrystalline and Amorphous Materials*. John Wiley and Sons Inc.,

New York.

- Krumbein, W.C. and Pettijohn, F.J. (1938) *Manual of Sedimentary Petrography*. D. Appleton-Century Co., New York.
- Krumbein, W.C. (1934) Size frequency distributions of sediments. *J. Sedim. Petrol.* 4, 65-77.
- Lewis, D.W. (1984) *Practical Sedimentology*. Hutchinson Ross Publishing Company, New York.
- Marshall, C. Edmund. (1977) *The Physical Chemistry and Mineralogy of Soils, Vol.2: Soils in Place*. John Wiley and Sons Inc., New York.
- McManus, John. (1988) Grain size determination and interpretation. In: Tucker, Maurice (ed.). *Techniques in Sedimentology*. Blackwell Scientific Publications, Oxford.
- Nickling William A. (1972) Recent loess deposits southwestern Yukon Territory: a systematic investigation of related source areas. Unpublished M.A. thesis, Geography Department, Carleton University, Ottawa.
- Pesci, M. (1968) Loess. In: Fairbridge, R.W. (ed.) *Encyclopedia of Geomorphology*. Reinhold Book Corp., New York.
- Rampton, V.N. (1981) *Surficial Materials and Landforms of Kluane National Park, Yukon Territory*. Geological Survey Paper 79-24. Ministry of Supply and Services Canada, Ottawa.
- Retzer, John L. (1974) Alpine Soils. In: Ives, Jack D. and Barry, Roger (eds.). *Arctic and Alpine Environments*. Methuen and Company Limited, London, 771-802.
- Ritter, Dale F. (1978) *Process Geomorphology*. William C. Brown Co., Dubuque.
- Ross, C.J., Wang, C., and Protz, R. (1984) Soil mineralogical evidence as an indicator of Post-Wisconsinan and Pre-Wisconsinan weathering in Canada. In: Mahaney, W.C. (ed.). *Correlation of Quaternary Chronologies*. Geo Books, Norwich.
- Ruhe, R.V. (1969) *Quaternary Landscapes in Iowa*. Iowa State University Press, Ames.

- Sheldrick, B.H. (ed.) (1984) *Analytical Methods Manual 1984*. Research Branch, Agriculture Canada, Ottawa.
- Stokes, G.G. (1851) On the effect of the lateral friction of fluids on the motions of pendulums. *Trans. Cambridge Phil. Soc.* 9, 8-106.
- Wang, C. (1991) Personal communication.
- Weast, R.C. (ed.) (1983) 64th ed. *CRC Handbook of Chemistry and Physics*. CRC Press, Boca Raton.
- Whittig, L.D. and Allardice, W.R. (1986) X-ray diffraction techniques. In: *Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods*. American Society of Agronomy - Soil Science Society of America, Madison, 331-363.
- Wormald, J. (1973) *Diffraction Methods*. Oxford University Press, London.

Appendix A

PARTICLE SIZE

DISTRIBUTION CURVES

Slims Valley and Kluane Lake

Loess Deposits

LOESS SITE SV 1

Particle Size Distribution

LOESS SITE SV 2

Particle Size Distribution

LOESS SITE SV 3 Particle Size Distribution

LOESS SITE SV 4

Particle Size Distribution

LOESS SITE KL 1

Particle Size Distribution

LOESS SITE KL 2

Particle Size Distribution

LOESS SITE KL 3

Particle Size Distribution

Appendix *B*

PARTICLE SIZE DISTRIBUTION CURVES Duke Valley Materials

TRANSECT 1

Particle Size Distribution

TRANSECT 2

Particle Size Distribution

TRANSECT 3

Particle Size Distribution

TRANSECT 4

Particle Size Distribution

TRANSECT 5

Particle Size Distribution

TRANSECT 6

Particle Size Distribution

TRANSECT 7

Particle Size Distribution

TRANSECT 8

Particle Size Distribution

2

of/de

2

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

TRANSECT 9

Particle Size Distribution

TRANSECT 10

Particle Size Distribution

TRANSECT 11

Particle Size Distribution

TRANSECT 12

Particle Size Distribution

END

27.05.92

FIN