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A STUDY OF POSTGLACIAL LOESS AND PALEOSOLS
IN THE LETHBRIDGE AREA OF SOUTHERN ALBERTA

by

RUTH ELIZABETH BARNES

A thesis submitted to the Department of Geography
in conformity with the requirements for
the degree of Master of Science

Queen's University
Kingston, Ontario, Canada

December, 1991

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ABSTRACT

A study of soils developed on Holocene loess was undertaken to determine the postglacial soil-landscape evolution near Lethbridge, Alberta. The post-glacial stratigraphy of a loess mantled area along the Oldman River was reconstructed from drill cores taken along five transects. Loess thicknesses and the extent of loess mantling in this area were determined to give an indication of the paleoenvironment. This study was interfaced with the known glacial history of the area to further study the extent of glaciation in southern Alberta. Glacier Peak tephra (ca. 11.2 ka) found at an elevation of 888m along the Oldman River indicates that Glacial Lake MacLeod which covered this area immediately following deglaciation must have drained by at least 11 200 years BP. The lack of a paleosol on the glaciolacustrine surface indicates that loess mantling must have begun immediately following deglaciation. Paleosols contained within the loess deposits indicate that at least twelve soil forming intervals occurred in this area since deglaciation.

The loess complex examined in this study was determined to contain two loess units: a lower, silt dominated unit and an upper, sand dominated unit. Rates of accumulation of the

two units were determined from two tephra beds, Glacier Peak tephra ca. 11.2 ka and Mazama tephra ca. 6.8 ka, which were used as datum levels. The relative chronology of the postglacial soil-landscape evolution and the soil forming intervals was determined. Soils were studied in terms of soil genesis and as stratigraphic markers.

Discussions focus on the implications of loess accumulation and soil forming intervals on the paleoenvironment.

ACKNOWLEDGEMENTS

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I would also like to thank Karen Stanley, Louise Broderson, Bruce Johnson and John MacCaskill for assistance during field work. Special thanks to Dr. Peter Stockdale former director of the Animal Diseases Research Institute of Agriculture Canada at Lethbridge, for permitting geological investigations on Institute terrain.

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CHAPTER 1
INTRODUCTION

1.1 Objective

The objective of this study is to document and analyze the imprints of 11 000 years of continuous geomorphological and pedological process activity in a postglacial, i.e. Holocene, loess landscape near Lethbridge, Alberta.

As such, this is a case study in soil-landscape evolution, a recognized and major part of Quaternary soil-geomorphology (Arnett *et al.* 1985). This study aims at reconstructing the sequence and chronology of geomorphic and pedological events that have shaped the surfaces of natural landscapes. This sequence is examined in relation to past climatic and ecological conditions. The evolution of loess landscapes in North American loess regions has received particular attention since the 1950's.

The study area is located in the Palliser Triangle (Figure 1.1), a region that coincides with the native Canadian grasslands of the Interior Plains and that includes most of Canada's wheatlands. The Palliser Triangle extends between the 49th and 52nd parallel, from longitude 100° to 114° and

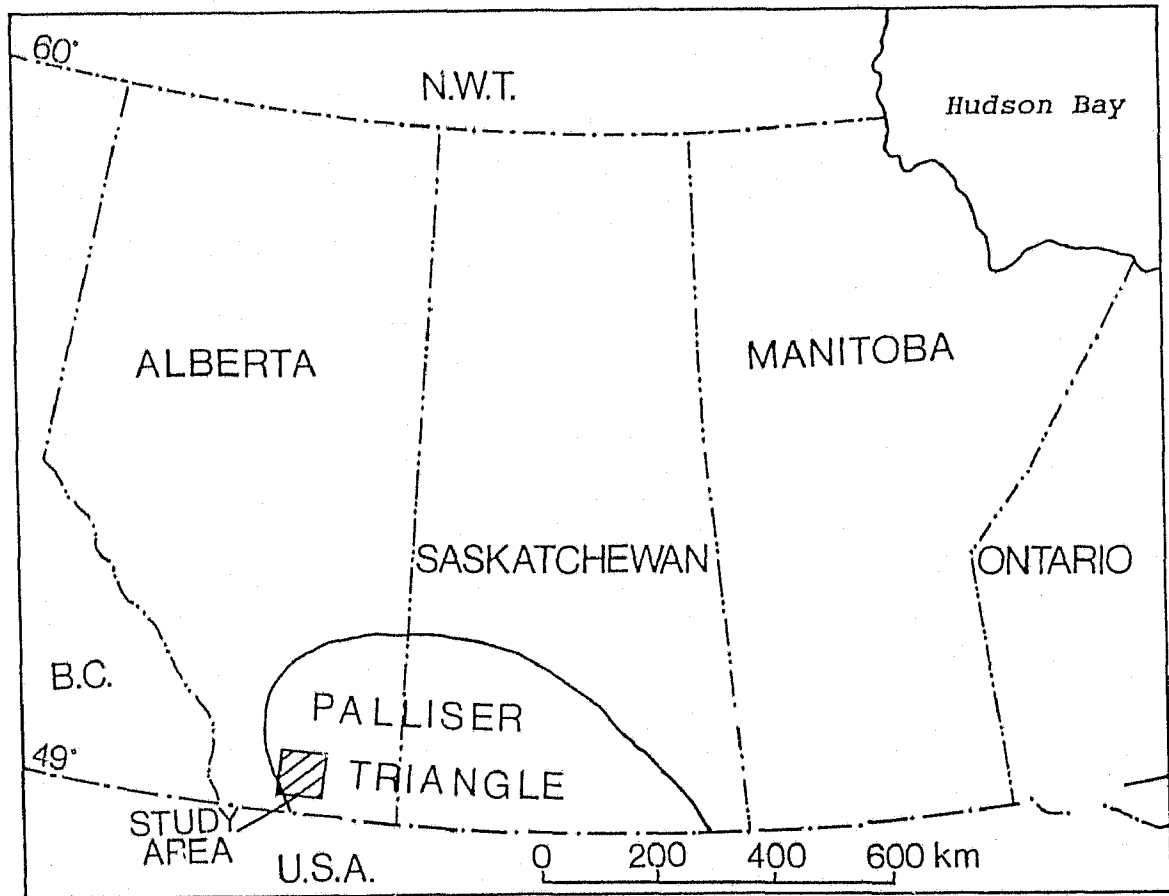


Figure 1.1. Location of the study area with reference to the Palliser Triangle, which coincides with the native Canadian grasslands of the Interior Plains (after Putnam and Putnam 1979).

was named after Captain John Palliser who explored it in 1857 to assess its agricultural potential. Palliser described this 20 million ha, low rainfall area as a desert, unsuitable for agricultural activity in view of recurrent episodes of drought (Anderson 1975).

Recently, in response to concerns about long term effects of global warming, a proposal* was set forth which would designate the Palliser Triangle as a global change monitoring area. This would represent an initiative to reconstruct the paleoenvironment of the past 10 000 years, and to reconstruct the climatic and natural conditions that occurred during that period. This information would then be used to develop scenarios for the response of the natural environment to anticipated global warming and the possible impact on human activities.

Given the objectives of this proposal, this study will be recognized as addressing key aspects of the proposed Palliser Triangle global change monitoring program.

*Note: This Geological Survey of Canada proposal was contained in a personal communication to Dr. W. Vreeken.

1.2 Loess landscapes and soil-geomorphology

Loess is defined as a widespread, homogeneous, commonly unstratified, porous, permeable, friable, slightly coherent, usually calcareous, fine-grained blanket deposit, consisting predominantly of silt with subordinate grain sizes ranging from clay to fine sand (Bates and Jackson 1987, Greeley and Iversen 1985). Not all loess deposits are silt dominated. For example, the vast loess deposits in northwestern China contain a large sand component (Derbyshire 1983), and the loess map for Europe depicts a special category denoting sandy loess (Haase *et al.* 1983). Postglacial loesses in southern Alberta also include sandy loam grade loess (Vreeken 1986). Nor are all loess deposits necessarily nonstratified, i.e. massive. Loesses in the Netherlands and Belgium show distinct lamination, attributed to reworking by water action, subsequent to aeolian deposition (Mucher and De Ploey 1977).

Many widespread loess deposits in North America and Europe date to the latest glacial stage and their origin is attributed to glaciation-related controls, notably the aeolian derivation from glacial meltwater deposits and a cool to cold climate. Loess deposits are also known in regions far removed from formerly glaciated terrain, and they accumulated in warm climates, such as in Israel (Rognon *et al.* 1987). Similarly, postglacial loess has been studied in Texas, U.S.A. (Holliday 1985) and it is common in the western Palliser Triangle (Catto

1983; Vreeken 1986; Pennock and Vreeken 1986). Indeed, Miocene loess, by far predating the Quaternary glaciations, has been identified and dated in the Cypress Hills of Saskatchewan (Vreeken and Westgate 1992). Postglacial loess deposits have received much less attention than the glacial ones and this study seeks to redress this situation.

Loess can be found on all kinds of sedimentary substrate and landscape positions. Loess mantling in the Palliser Triangle of southern Alberta occurs mainly on the uplands where it is extensive but discontinuous. Loess thicknesses are up to 6.7 m maximally in the area studied. Loess tends to cover the underlying topography thereby effecting a reduction of relief, or a smoother surface on which subsequent deposits occur. Thus, the underlying topography may actually be very different from the present-day land surface.

Loess sequences are the best media for the preservation of subaerially developed soils because loess can accumulate on subaerial surfaces, where it tends to be deposited without a preceding phase of erosion, such as tends to be the case with waterlaid sediments. These loess-mantled as well as intra-loess soil mantles can be valuable indicators of past climates and environments. The very presence of buried soils within loess sequences indicates changes in environmental conditions that permitted soil formation. Paleosols also serve to

separate major loess deposits which would otherwise be viewed as a single depositional body (Ruhe et al. 1971). Used as stratigraphic markers, paleosols serve as reference levels to calculate rates of loess accumulations before and after their formation. These are the major reasons why loess landscapes have received so much attention from paleopedologists and soil-geomorphologists.

Finally, accumulation is a consequence of loess transportation and, prior to that, of loess derivation from a source. Understanding a loess body entails knowing, or at least attempting to reconstruct, the dispersal system that produced it. This study addresses the loess near Lethbridge from that perspective.

1.3 Scope of study and structure of the thesis

The purpose of this research is to document a loess site in the Lethbridge area. Initially, it was necessary to determine if there was a site in this area with sufficient loess thicknesses to be worth further investigation. This involved two steps. First, a considerable amount of reconnaissance work was required to locate, and describe a suitable site. Secondly, it was necessary to analyze the three-dimensional subsurface variability of that site, in order to lay the foundation for documenting a loess dispersal system. This subsurface analysis required documenting the

loess stratigraphy, which was done from borehole data combined with outcrop data. Relative age relationships between landforms, sedimentary units, and paleosols were complemented with absolute age criteria offered by tephra beds. The laboratory work was done to characterize intrinsic properties of sediments and soil materials, and to verify morphological criteria that were used in the field.

Chapter two of this thesis addresses the setting of the study area and a review of previous work. Chapter three deals with the methods used in the field and in the laboratory. The reconnaissance in search of loess sequences is described in chapter four. Chapter five discusses the loess sequences from the detailed study site, which was near Kipp, Alberta. The soils developed in the loess are addressed in Chapter six. The final chapter gives a synthesis of the geomorphic and pedological evolution and presents final conclusions of the study.

CHAPTER TWO

SETTING OF THE STUDY AREA AND PREVIOUS WORKS

This chapter addresses the setting of the study area in terms of geologic and Quaternary history, vegetation, climate, and soils.

2.1 Bedrock Geology

The landscapes of southern Alberta are underlain by subhorizontal sedimentary rocks of Late Cretaceous age (Beaty 1975a), locally overlain by remnants of Tertiary formations (Table 2.1). Bedrock exposures in the Lethbridge area are confined to the walls of deeply incised valleys. In the Oldman Valley, these exposures reveal the Bearpaw Formation near the town of Kipp and the Oldman Formation near Lethbridge, but the Tertiary formations are absent. The Bearpaw Formation is a shale and sandstone marine formation with concretionary ironstone and bentonite beds. The Oldman Formation is nonmarine and consists of sandstone with siltstone, mudstone, and shale with concretionary ironstone beds. An erosion surface, overlain by Quaternary gravels marks the top of the bedrock (Green 1970).

The bluffs near Kipp along the Oldman River are shown in Figure 2.1. Cretaceous shales with some calcareous sandstones

Geologic Time Scale	General Stratigraphy of Southeastern Alberta	Present in Southern Southwestern Alberta	Present at Kipp Site
Holocene			Loess complex
			Glaciolacustrine silt and clay rhythmites
			lacustrine Lenzie silts
Quaternary Pleistocene			Till complex -Brocket till? -Maunsell till? -Labama till?
Tertiary Miocene Oligocene	Cypress Hills Formation		Prefaunentide fluvial gravels
Paleocene		Porcupine Hills Formation	
Tertiary and Cretaceous Paleocene	Ravenscrag Formation	Willow Creek Formation	
Cretaceous Upper Cretaceous	Whitemud and Battle Formations	Whitemud and Battle Formations	Cretaceous shales -calcareous sandstone
	Eastend Formation	St. Mary River Formation	-oxidized gravels
	Bearpaw Formation	Blood Reserve Formation	
	Oldman Formation	Bearpaw Formation	Bearpaw Formation
	Foremost Formation	Oldman Formation	
	Pakowki Formation	Foremost Formation	
	Milk River Formation	Pakowki Formation	
	Alberta Formation	Milk River Formation	
		Alberta Formation	

Table 2.1. Geological Formations of southern Alberta. (after Green 1970)



Figure 2.1. The Kipp site located along the Oldman River, 5.5 km northwest of the city of Lethbridge. The bluffs at the Kipp site show the Bearpaw Formation and Cretaceous shales with some calcareous sandstones at the base (A). Bedrock materials are overlain by Quaternary gravels (B) of unspecified age. A till complex (C) covers the gravels, overlain by lacustrine Lenzie silts, the light yellow sediment near the top of the bluffs (D). Glaciolacustrine silt and clay rhythmites (E) cover the silts and a loess complex (F) caps the sequence. The dotted line on the left of the photograph is actually a radio tower, located on the site.

are located at the base. Bedrock materials are overlain by Quaternary fluvial gravels of unspecified age. Horberg (1952) referred to these gravels as the Saskatchewan Gravels. They likely predate the Laurentide glaciations because they do not contain igneous and metamorphic clasts that would have originated from the Canadian Shield (Stalker 1968, 1983). These gravels were deposited in a preglacial valley, forming part of a regional stream drainage network that was partially exhumed during postglacial times. The minimum age estimates for these ancient gravels is set by their post-depositional modifications and by the maximum age of their overburden. Horberg (1952) reported the presence of an oxidized weathering zone in the top of the gravels and remnants of a paleosol, apart from crossbedding and some sand lenses. The upperpart of these gravels has deformation features attributed to periglacial processes (Horberg 1952) and is overlain by the glacial sequence, consisting of Cordilleran till. This Cordilleran till is not represented near Lethbridge or farther eastward. Various Laurentide glacial deposits are represented in peak thickness near Kipp and Lethbridge. Their temporal placement, however, is controversial and reflects different opinions on the maximum extent of the Late Wisconsin Laurentide ice sheet. Overlying this till complex are pale lacustrine Lenzie silts followed by Glacial Lake MacLeod clayey rhythmites. Capping the rhythmites is a loess complex.

2.2 Quaternary Geology

The landscape of southern Alberta for the most part is mantled by glacial and post-glacial debris. Figure 2.2 shows the surficial geology for the Lethbridge-Kipp area. In this area, the landscape is covered by fine-grained lake deposits consisting mainly of silt with some minor occurrences of clay. Near Kipp, hummocky moraine, with minor occurrences of recessional moraine, mantles the area. In the incised river valley, alluvium of modern stream deposits includes gravel, sand and silt. The thick aeolian deposits near Kipp were not mapped by Stalker (1962) and are not shown in Figure 2.2.

The southern Interior Plains experienced several glaciations with glaciers reaching southern Alberta from the Cordillera and from the Laurentide Shield. During the Late Wisconsinan glacial stage, ice advanced to this area from two directions. The Laurentide ice sheet advanced across the Canadian Shield from the north and east, while Cordilleran ice originating in the Rocky Mountains advanced from the west (Klassen 1989). These sheets converged in the southern part of the Interior Plains sometime around 18 000 BP (Dyke and Prest 1987). At this time Cordilleran ice was likely already retreating when the Laurentide ice reached its maximum because of the asynchrony of the rates of retreat of the two ice sheets (Stalker 1980). This coalescence also probably marks the last major glacial advance in this area. However, the

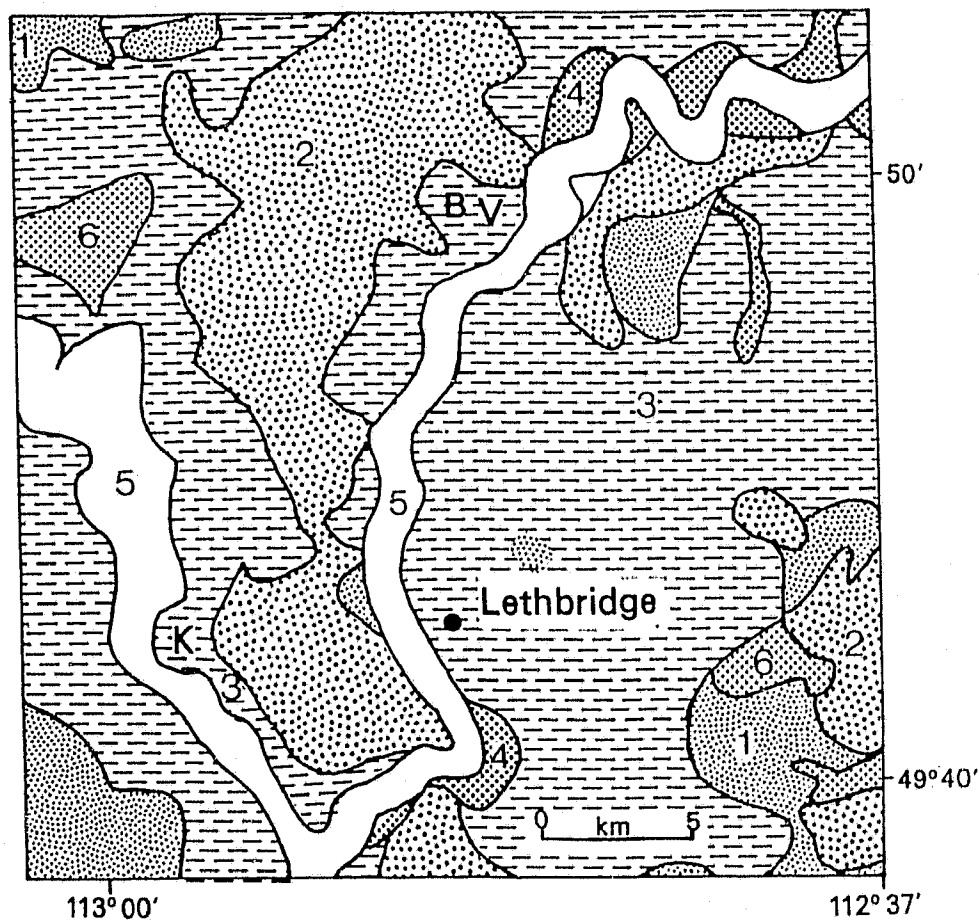


Figure 2.2. Surficial geology of the Kipp and Lethbridge area. Map units: 1, ground moraine (till); 2, hummocky moraine (till) with minor occurrences of recessional moraine; 3, lake deposits, fine (silt, minor clay); 4, alluvium, coarse (postglacial terrace deposits) (gravel, sand, silt); 5, alluvium of modern streams (gravel, sand, silt); 6, wind deposits (sand, silt). Sites: K, Kipp; B, Barron; V, Van der Heyden. (after Stalker 1958 and 1962).

maximum extent of this last advance is uncertain.

2.2a Maximum extent of Laurentide Wisconsinan ice

Stalker (1977) placed the maximum extent of the late Wisconsinan Laurentide ice sheet in the Canadian Prairies at the Lethbridge Moraine (Figure 2.3), believing it was formed around 22 000 BP. However, Horberg (1952) and other workers placed the limit further south, into Montana. Similarly, Shetsen (1984), Clayton and Moran (1982), and Klassen and Vreeken (1987) believe that the Lethbridge moraine marks only a position of readvance. Laurentide glacial deposits found south of the Lethbridge moraine would be pre-late Wisconsinan according to Stalker's model, but they would include late Wisconsinan drift according to many other workers. Shetsen (1984) places the extreme limit further south past the Lethbridge Moraine on the basis of pebble lithologies, citing the lack of evidence that till composition and the till sequence change south of the Lethbridge Moraine (part of Shetsen's Margin 3). Vreeken (1986) concluded from stratigraphic and tephro-chronological evidence that late Wisconsinan drift extended beyond the location of the Lethbridge Moraine in southeastern Alberta, thus confirming a proposal of Westgate (1968). This was supported by Klassen and Vreeken (1987) who estimated a 12 630 BP radiocarbon age for freshwater shells from moraine plateau sediment at a site southeast from the Cypress Hills in Saskatchewan.

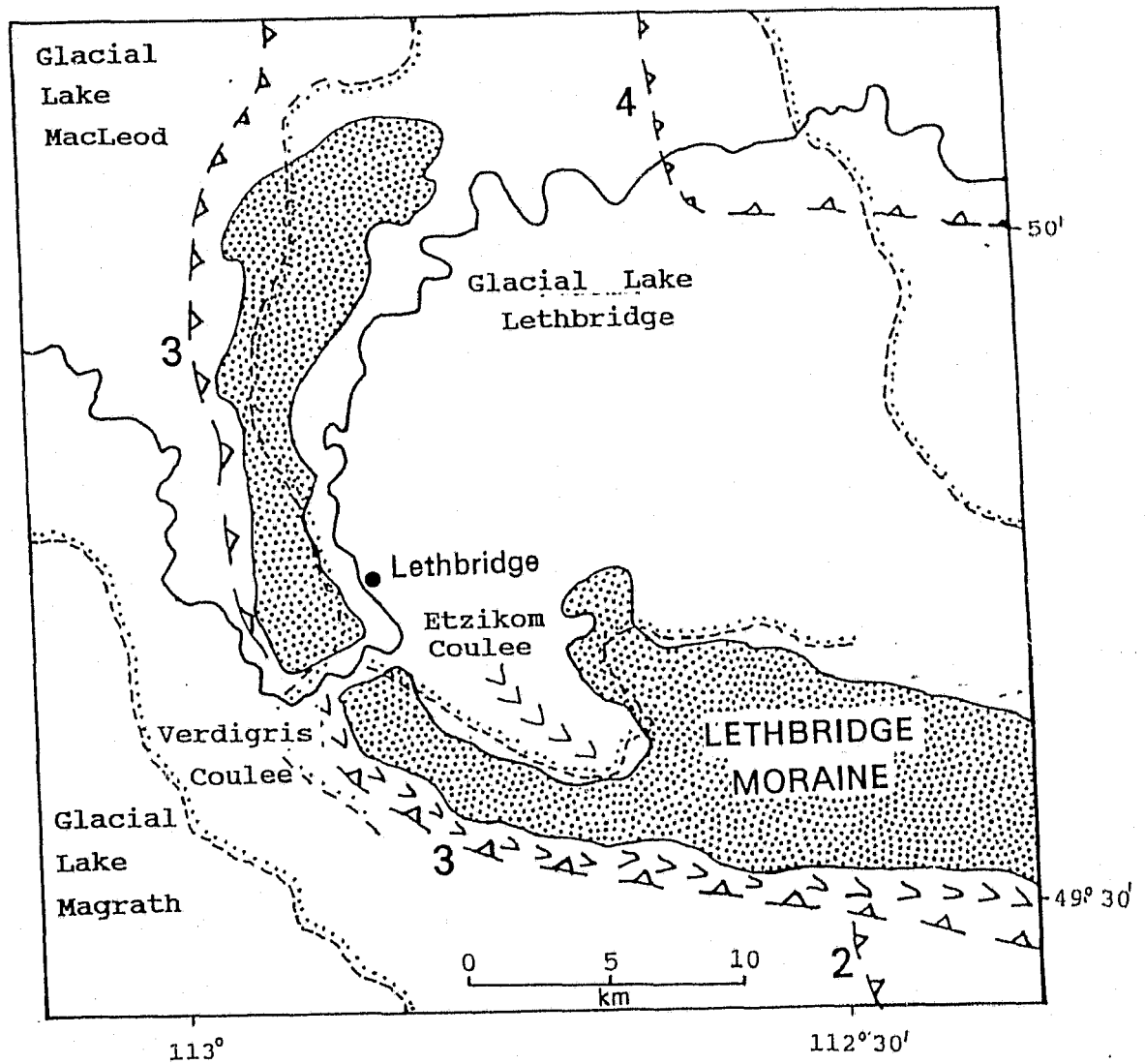


Figure 2.3. Glacial map of southern Alberta. Ice front positions ($\Delta\Delta$) are shown and numbered, after Shetsen (1984); Glacial lakes and limits ($\cdots\cdots$) after Horberg (1952); Lethbridge moraine position after Shetsen (1987); Verdigris Coulee and Etzikom Coulee (\gggg) after Beaty (1975b).

Vreeken (1989) gives proof that the area was deglaciated at approximately 13 510 BP with a radiocarbon date on shells taken from the uppermost sediments of glacial Lake Downie at a site in southern Saskatchewan, indicating that deglaciation of the Lethbridge moraine must have been between 13 510 and 11 200 BP. Fullerton and Colton (1986) also found what they believed to be late Wisconsinan deposits south of the Lethbridge moraine, indicating that Laurentide ice advanced beyond the position of the Lethbridge moraine. Therefore, it seems reasonable to place the maximum extent of the late Wisconsinan Laurentide ice sheet south of the Lethbridge moraine.

2.2b Glacial lakes During deglaciation, as the Laurentide ice margin retreated to the north and northeast, down the regional slope, proglacial lakes formed at successively lower elevations (Figure 2.4). The elevations of these lakes were set by the elevations of a series of outlets that allowed water to escape around the margins of the ice into the Missouri drainage basin (Horberg 1952). These outlets are recognized as the coulees that now dissect the southern Alberta landscape.

The lakes were relatively short-lived, shallow water bodies that collected water from the melting glacier and from progressively more extensively deglaciated terrain. They

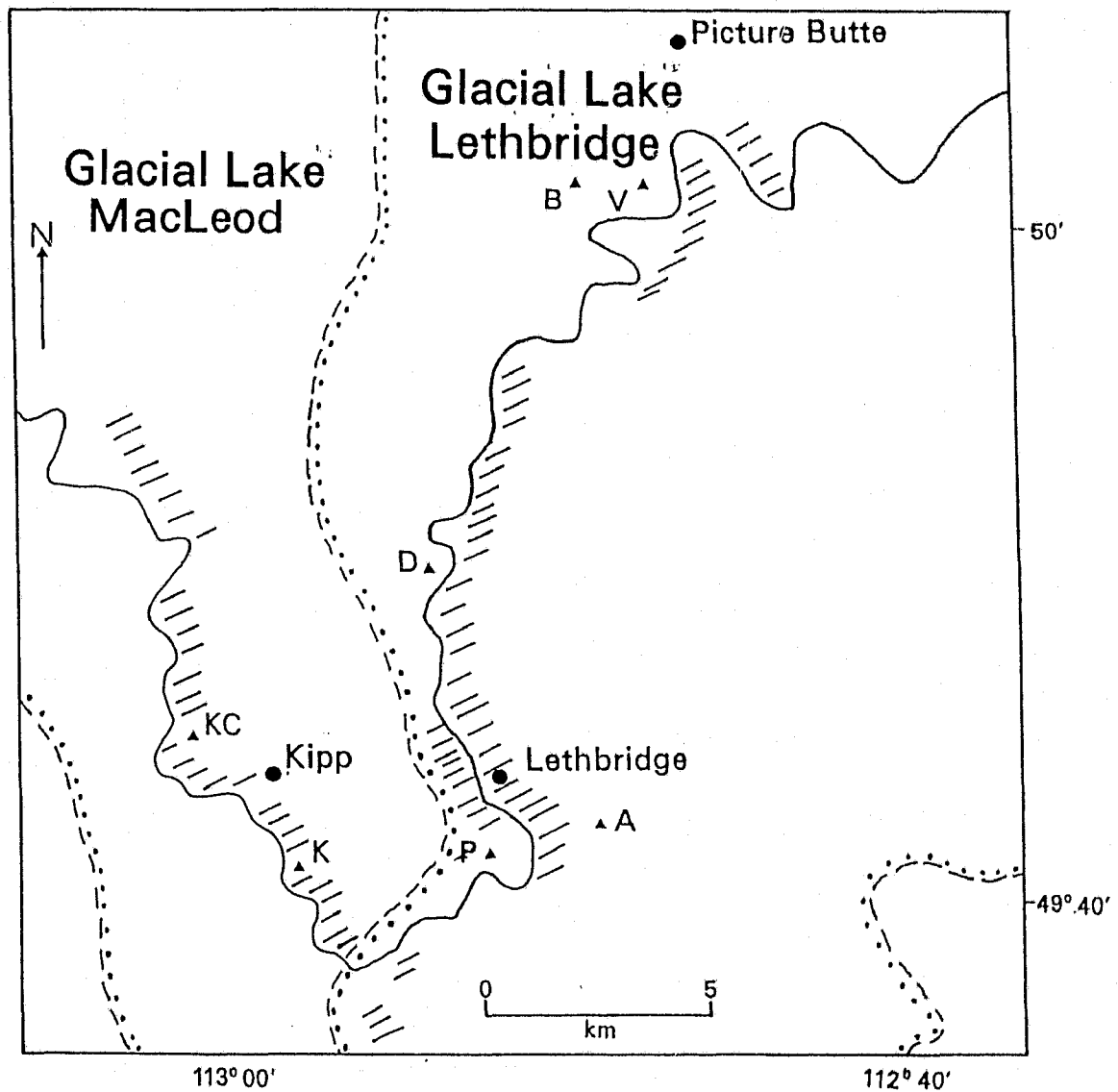


Figure 2.4. Glacial map of Lethbridge area showing location of reconnaissance sites and detailed study site, and the delimitations of glacial lakes MacLeod and Lethbridge (after Horberg 1952). Short straight lines denote straight, aligned minor coulees, tributary to the Oldman River (after Beaty 1975a). Sites indicated are as follows: B, Barron; V, Van der Hedyen; D, Diamond City; A, Airport; P, Popson Park; K, Kipp; KC, C&P Crushing.

ponded between the higher ground to the west and the edge of the retreating ice mass so that their lake levels fell to successively lower elevations (Beaty 1975b). Glacial Lake MacLeod is represented in the Kipp area, while in the Picture Butte/Lethbridge area Glacial Lake Lethbridge existed following further retreat of the Laurentide ice margin. Glaciolacustrine silts and clays, present at all of the sites of this study, were deposited in these basins during this period.

2.2c Drainage of the glacial lakes Once ice retreated to a sufficiently low elevation, the successive glacial lakes drained through the outlets. Glacial Lake MacLeod drained through Verdigris Coulee, while Glacial Lake Lethbridge drained through Etzikom Coulee (Figure 2.3) (Horberg 1952). Freshwater shells from proglacial lake sediments that accumulated at a site in Saskatchewan while the Lethbridge moraine formed the ice margin are 13.5 ka old. This suggests that sediments from Glacial Lake MacLeod are probably of the same age (Vreeken 1989). Sediments from Glacial Lake Lethbridge are necessarily younger but they accumulated before 11.2 ka, which is the age of Glacier Peak tephra found within loess on top of those sediments (Vreeken 1989). Therefore, drainage of the lakes must have occurred sometime between 13.5 ka and 11.2 ka.

2.2d Late Wisconsinan ice-free corridor Discussion

of the maximum extent of ice in southern Alberta must include consideration of the concept of an "ice-free" corridor. The possible presence of an ice-free corridor was initially introduced as a pathway for migration of the people of southern North America who suddenly appeared on the continent about 13 000 BP (Stalker 1980). They are believed to have crossed from Asia into North America via a land bridge, called Beringia, located between what is now Siberia and Alaska. This area was thought to be a staging area for both man and other animals, along with some vegetation species. Beringia is believed to have been ice-free during the last glaciation and thus would have provided a refugium for plants and animals. However, Jennings (1983) and other workers believe that North America was peopled by 30 ka and maybe as early as 65 ka. It is also suggested that human migration into North America may have followed a coastal route, largely negating the need for an ice-free corridor at 13 ka (Fladmark 1978).

Stalker (1980) discusses the possibility of an ice-free corridor between Laurentide and Cordilleran ice, except during maximum advances. His theory that the Late Wisconsin glacial stage did not extend as far as previous stages and that the final retreat of the ice from this area occurred around 22 000 BP would seem to support the presence of an ice-free corridor at ca. 19 000 BP. Stalker and Harrison (1977) introduced a

"zipper" theory whereby, during successive glaciations, Laurentide ice advanced and retreated periodically at a nonsynchronous rate with Cordilleran ice, which appears to have been in active retreat by the time the Laurentide ice reached its maximum. The "zipper" would open from south to north when ice began to wane and would close from north to south when the ice advanced again. Stalker (1980) believed that Laurentide ice advanced shorter distances with each glaciation and, by the third and fourth glaciations, little if any closure occurred in Alberta. Stalker (1980) believed the last glacial advance of Laurentide ice was the least extensive. He placed its limits to the east of Calgary and advocated that it reached its maximum extent around 17 000 BP. Thus, the largest corridor between the ice sheets would have existed ca. 13 000 BP.

Shetsen (1984), however, placed the western limit of the last Laurentide ice advance west of Calgary. Pebble lithologies indicate that ice advancing from the east was blocked by ice advancing from the west out of the mountains. Once this Cordilleran ice began to wane and retreat, Laurentide ice advanced farther westwards to a point just west of Calgary (Shetsen 1984). This implies a stronger Laurentide advance than was advocated by Stalker. Clayton and Moran (1982) place the Laurentide ice sheet west of Calgary during their phases F, G, and H and place a date of 14 000 BP to 13

500 BP on this position. By 12 300, during their phase I, the Milk River had become exposed and the ice sheet was approximately at or just east of the Lethbridge moraine. By 11 700 BP, Laurentide ice had retreated farther northeast, exposing both Verdigris and Etzikom coulees, which allowed for drainage of Glacial Lakes MacLeod and Lethbridge around this time. Also, Klassen and Vreeken (1987) have shown that the minimum date for ice retreat is ca. 13 000 BP and the lack of an apparent soil forming interval in this area would seem to indicate that deglaciation did not occur much before this time. Therefore, it seems unlikely that an ice-free corridor existed in the Alberta Foothills ca. 13 000 BP.

2.2e Loess Immediately following deglaciation, loess mantling began in the Lethbridge area. This is indicated by the lack of a paleosol developed from glaciolacustrine deposits directly beneath the loess. Loess mantling in this area is extensive, but discontinuous. Initial observations in the Lethbridge area indicated that loess was distributed mainly along the Oldman River and its tributary coulees. Stalker's 1958 and 1962 surficial geology maps of this area show aeolian deposits northwest and east of Lethbridge; however, none is indicated along the Oldman River. The soil map of the Lethbridge area refers to fine-loamy to fine-silty lacustrine or fluvial material along the river, and indicates that these sediments can be referred to as glaciolacustrine.

Vreeken (1989), however, reported finding 6.7 m of loess at a site directly along the Oldman River. The presence of Glacier Peak tephra layer G near the base of the loess indicates that loess accumulation began just slightly before this date, following drainage of Glacial Lake MacLeod, and therefore indicates that this area must have been deglaciated sometime before 11 ka (Vreeken 1989). Thick postglacial deposits, such as loess, can help date glacial or glaciolacustrine substrates by tephrochronological and paleopedological techniques (Vreeken 1989). Dating of the glaciolacustrine sediments in the sites of study will be examined in a later chapter.

2.2ei Loess origin The origin of loess material, which is preferentially silt-size, is largely unknown. Several hypotheses have been advocated including glacial, periglacial, and aeolian abrasion, several forms of weathering, and sorting during recycling. Many workers favour a periglacial origin, but others advocate a hot desert origin for some loess materials. Smalley (1966) proposed that loess material was formed by glacial grinding. Bolton (1978) further suggests that this grinding occurs in the basal zone of glacial traction where "large forces at non-inertial shear contacts produce fine-grained wear products" (Bolton 1978, p. 796). Others, however, advocate that some loessic silt is derived from "hot desert processes". Whalley et al. (1982) suggest sand grain impact as a possible origin. However, this

was not supported by Kuenen (1960) who did aeolian abrasion experiments and found that only fine silt material was produced. Another possible hypothesis for the origin of these silt-sized particles is put forth by Nahon and Trompette (1982) who suggest that chemical weathering is an active agent whereby weak minerals are removed through dissolution and quartz is fragmented by partial chemical dissolution. Goudie *et al.* (1979) also support chemical weathering in the form of salt weathering with sodium sulphate as the dissolution agent. Another possible path of origin for these silt-sized particles is through frost processes. Zeuner (1949) conducted studies on Mount Kenya and found that frost processes were a significant factor in producing loess material. This process would seem to support a periglacial origin for much loess material.

It must be considered, however, that different origins of loess material may be applicable in different frameworks. Recycling is always possible, as is the case with the loess found in the northern Negev (Israel) which has been studied microscopically and appears to be the product of several different sources. The loess appears to have been progressively weathered and reflects a high degree of recycling (Rognon *et al.* 1987). Glacial or periglacial origins are not likely for areas that never experienced the prerequisite environment and processes, such as the loess-

mantled areas of Lishi, China containing loess tens of metres thick, which date to the Pleistocene (Luk *et al.* 1989).

The Cypress Hills contains loess which dates to the late Tertiary (Vreeken *et al.* 1989), which accumulated before glaciation in this area, thus the source of the loess material cannot have been glacial or periglacial processes. The origin of loess material examined in this study will also be briefly addressed in subsequent chapters.

2.2eii Source of loess Determining the source of a loess body can indicate the direction of transport of that material. This in turn can help to explain changes in the texture of the deposit, thereby increasing the information on the dispersal system. Catto (1983) studied loess deposits in the Cypress Hills area of Alberta and determined that they were probably formed from a single source area located adjacent to the southwest margin of the plateau, indicating that the direction of transport was likely from southwest to northeast.

Handy (1976) studied loess deposition by variable winds. He postulates that systematic decreases in loess thickness away from a linear source usually attributed to a prevailing wind direction may instead be a result of variable wind directions and he presents a mathematical model to explain this. The resultant distribution pattern of loess thickness

contour lines is approximately parallel to the linear source, curving outwards to reflect the effect of prevailing wind directions. However, this model does not account for interference from topographic obstacles. Deposition of loess by prevailing winds or variable winds in the Lethbridge area will also be addressed in a subsequent chapter.

2.3 Vegetation

The native vegetation of southern Alberta is mixed prairie grassland (Clayton *et al.* 1977a). The evolutionary history of this plant association is poorly understood, mainly because of unreliable records of plant macrofossils, pollen, or spore assemblages. This lack is not due to a paucity of postglacial sediment sequences as much as it is a corollary of the poor preservation potential of these fossils under oxidizing conditions. These conditions appear to be inherent to semi-arid climatic conditions that have prevailed in much of the Palliser Triangle during postglacial times.

By contrast, pollen records from the aspen parkland and boreal forest regions of central Alberta show less evidence of selective preservation of certain pollen species. The latter records must serve as proxy data for the vegetation history of southern Alberta.

2.3a Postglacial vegetation history

2.3ai The pollen record The pollen record for central Alberta indicates that, following deglaciation, the earliest pollen zone was significantly non-arboreal. It consisted mainly of *Gramineae*, *Cyperaceae*, and *Artemisia*, while *Populus* also was present in differing amounts in some areas (Vance 1986). This early postglacial assemblage, referred to as tundra-like by Mott and Jackson (1982), was replaced by a *Picea* dominated assemblage, in places with a significant amount of *Betula*, in deposits from the 12 to 10 ka interval (Vance 1986). Between approximately 9 and 6 ka grassland in central Alberta expanded northwards, as indicated by fossil pollen and diatom studies. Lower lake levels in central Alberta and increased frequency of fires suggest this was a period of severe drought (Vance 1986). About 9250 BP, the *Picea* dominated assemblage was replaced by *Ruppia*, a hypersaline indicator species indicative of lower lake conditions. Around 7500 BP, the pollen assemblages of *Pinus* and *Alnus* also appeared in central Alberta (Vance 1986). Increased saline conditions and evaporation stress lasted until approximately 3000 BP, with peak frequencies of pollen occurring in sediments dated 7000 to 3000 years BP (Schweger and Hickman 1989). By 3500 BP grassland had retreated southward to its present position (Vance 1986) and by 3000 BP modern day conditions existed.

According to the general climate circulation model put forth by Kutzbach and Guetter (1986) the northern midlatitudes experienced warmer summers and colder winters during the period 12 000 to 6000 BP. Experiments with atmospheric general circulation models (AGCM) for the period around 9 ka indicate substantial increases in precipitation due to enhanced monsoonal responses to changed orbital forcing reflected in solar radiation conditions. However, this increase in precipitation was accompanied by an even greater increase in evaporation, resulting in a warm, dry early to mid-Holocene period. Solar insolation in the northern hemisphere may have been 8% greater in July and approximately 8% less during January during this period when compared with present-day conditions (Kutzbach and Guetter 1986). Between 9 and 6 ka temperatures were approximately 1°K warmer in July and 0.5°K cooler during January than the present due to increased seasonality (Kutzbach and Guetter 1986). Conditions following this period appear to be precursors to modern-day conditions.

Schweger and Hickman (1989) cored lakes and bogs in central Alberta to address the Holocene paleohydrological record and to provide an independent record that could be used to test the validity of general climate circulation models. Cores taken from lakes and bogs in central Alberta indicate that, during the early Holocene, arid conditions existed.

They also confirmed the findings of Kutzbach and Guetter (1986) and Schweger and Hickman (1989) that the early to mid-Holocene was a period of aridity. Schweger and Hickman (1989) also found pollen and diatom evidence that shallow basins, which had been empty during the early Holocene, began to fill around 8000 BP, coinciding with the onset of moister conditions indicative of modern-day conditions. This evidence supports the premise of Kutzbach and Guetter (1986) that this period was one of increased precipitation. By 8000 BP, many of the basins contained permanent water, suggesting that the balance between evaporation and precipitation had changed and, by 5000 BP, many shallow basins had filled. The climate had become much wetter. By 3000 BP, modern day climate conditions were in place (Schweger and Hickman 1989).

Mott and Jackson (1982), from their work at Chalmers Bog in the foothills of southern Alberta, found that the earliest vegetation types in this part of southern Alberta following deglaciation were indicative of a sparsely vegetated area, which they identified as tundra rather than grassland. Mosses, including *Drepanocladus exannulatus* and *D. crassicostatus*, were present in shallow water and in the wet areas surrounding the lake at the study site. Pollen located in the overlying layer (850 cm) indicated that grasses and sedges, including *Artemisia* and *Cyperaceous*, populated this area along with *Salix* and *Alnus*, but *Pinus* and *Picea* were not

present as they were in central Alberta. Following this layer, the pollen assemblage indicates that the grasses and sedges declined as birch and pine began to invade this area. The presence of *Typha* or cat-tails pollen following the above assemblage indicates that the lake basin was becoming shallower and marl deposition began to occur. The submergent aquatic taxa then began to be replaced by emergent taxa, indicative of infilling in the basin caused possibly by drier climatic conditions (Mott and Jackson 1982). This drier period could possibly correspond with the dry period suggested by the atmospheric general circulation model (AGCM) (Kutzbach and Guetter 1986), which is representative of the onset of the Hypsithermal ca. 9000 BP, proposed by some workers. The marl is overlain by peat; the marl-peat boundary gave a radiocarbon date of 8220 +/- 80 years BP on the basal 6 cm of peat (GCS-2851). A tephra layer located at a depth of 625 cm is considered to be Mazama tephra (6600-7000 years BP) by Mott and Jackson (1982). A change in the pollen assemblage also occurs at this time, with pine and spruce declining, while birch and grasses again increased in frequency. Above this level, the pollen assemblages remain much as they are today (Mott and Jackson 1982).

MacDonald (1982) studied sediment and peat from a bog in the Morley Flats area of southwestern Alberta. He found that the early species to invade the area following deglaciation

were the aggressive, pioneer species such as sedges and grasses, accompanied by willow and alder. This assemblage appears to have been followed by a *Pinus* and *Picea* (pine and spruce) dominated assemblage established by approximately 10 000 BP (MacDonald 1982). The *Picea* maximum occurs after the mid-Holocene and appears to decline after the deposition of Mazama tephra (MacDonald 1982). This maximum corresponds with a mid-Holocene climatic maximum which has been detected by all recent palynological investigations. Most workers have correlated this climatic maximum Hypsithermal of Deevey and Flint (1957). The length of this climatic amelioration is dated 9.2 ka until 3.5 ka by Lichti-Federovich (1970); however, most reports conclude that the climatic trend began sometime after the establishment of pine and spruce and continued until shortly after the deposition of Mazama tephra (MacDonald 1982). Thus, warm, dry conditions existed in southwestern Alberta from approximately 9000 to 7000 BP.

To summarize, the vegetation history of central Alberta following deglaciation appears initially to have comprised sedges and grasses, possibly with some willow and alder, indicative of tundra or grassland conditions. Spruce and pine dominated assemblages were established by 10 ka. By 9 ka, a period of increased precipitation began, accompanied by an even greater increase in evaporation. This resulted in an early to mid-Holocene period of warmer and drier conditions,

supporting an aquatic plant assemblage of emergent taxa. By 6 ka cooler and moister conditions were again established, capable of supporting grasses and birch; by 3 ka, conditions analogous to modern-day existed.

2.3b Calibration functions It would seem likely that the vegetation history of southern Alberta would follow a similar pattern to that of central Alberta; however, the records cannot be arbitrarily transferred to southern Alberta due to the influence of local factors such as geology and physiography. Other factors such as soil conditions and climate also affect plant dispersal and distribution. However, climate changes will have the largest effect on the vegetation species that populate an area (Terasmae 1973), although vegetation zonation changes will not occur immediately, but will lag behind changes in climate. The rate at which differing vegetation species migrate will not be equal. There will be periods of transition where many vegetation types that would not normally coexist under the same conditions will share the same zone. This lag in plant migration is one reason why calibration functions cannot be used for conditions before 7.5 ka (Vance 1986).

Calibration functions providing quantitative correlations between pollen frequencies for selected species and climatic parameters have been obtained for central Alberta under the

assumption that climate is the ultimate factor that causes changes in vegetation and thus in pollen records (Vance 1986). A linear relationship between pollen and climatic variables is inferred (Webb and Bryson 1972). The applicability of such calibration functions is limited to areas and to pollen species that exhibit strong correlation between pollen and climate, as is the case in certain forested areas (Ritchie 1983). But, Ritchie (1983) also showed that not all pollen taxa exhibit a linear relationship with climate. This may be because there is not, and has never been, a climatically determined equilibrium between the range of a species and environmental variables. There may be significant environmental lag effects in the pollen record. This may explain why correlations do not continue from forested areas beyond the tree line into the grasslands. Therefore, calibration functions established in central Alberta are not necessarily applicable to pollen assemblages that might be found in southern Alberta.

2.3c Radiocarbon dates from aquatic mosses The problems of unreliable radiocarbon dates and of modern vegetation analogues is illustrated by some of the conclusions reached by Mott and Jackson (1982) from their work at Chalmers Bog in the Foothills of southern Alberta. They attempted to construct a palynological record for southern Alberta and address the possibility that an ice-free corridor existed ca.

18 000 BP near the Foothills. Radiocarbon dates on the moss fragments *Drepanocladus crassicosatus* taken from below the marl layer, gave a date of 18 300 +/- 380 years BP, suggesting that this area was ice-free at this time. However, MacDonald et al. (1987) studied terrestrial plant macrofossils and aquatic bryophyte samples of *Drepanocladus* to assess the reliability of radiocarbon dates on aquatic moss. Their results showed that radiocarbon dates on aquatic mosses were systematically erroneous. These dates were 1400 to 6400 years older than dates obtained from terrestrial plant macrofossils. The relationship was not linear, but internally consistent with the greatest difference between the two species occurring near the base of the core. The differences are attributed to the incorporation of ^{14}C -deficient carbon by the mosses (MacDonald et al. 1987). The reliability of radiocarbon dates from aquatic mosses is therefore uncertain and they cannot be used to establish the presence of an ice-free corridor.

2.3d Selective preservation of pollen The problem of selective preservation of pollen further complicates the reconstruction of the vegetation history of southern Alberta. The southern prairies with their limited rainfall and dry conditions, and high aeolian activity are not conducive to the preservation of pollen assemblages or plant macrofossils. The lack of modern analogues for many of the pollen assemblages also complicates the pollen record. Furthermore, climatically

induced shifts in vegetation boundaries are not necessarily reflected in the composition of vegetation well within the vegetation zone (Terasmae 1975).

2.3e Vegetation history of southern Alberta In spite of all the reservations expressed above, a conservative outline can be provided for the vegetation history of the southern Alberta plains. Vegetation species represented soon after deglaciation may have included bryophytes, particularly mosses, and herbaceous plants. These species would have been followed by sedges and grasses, along with some willow and alder. It cannot be inferred whether this assemblage would have characterized a tundra or an early grassland environment. This early phase could have been followed by a decline in the grasses and sedges, with pine and birch invading the area, followed by spruce. Different species would have dominated different portions of the landscape, in accordance with differences in local drainage conditions. The conditions then appear to have become drier as lakes appear to have become shallower. This is reflected in the pollen assemblage which is dominated by pollen of an assemblage of mainly emergent taxa. These drier conditions possibly represent the onset of the Hypsithermal ca. 9000 BP. These warmer, drier conditions appear to have been followed by wetter conditions where pine and spruce declined and birch and grasses began to again populate the area at approximately 8 ka until 6.5 ka.

Following this period, the pollen assemblages are much as they are today, indicative of the arrival of modern conditions by about 3 ka (Mott and Jackson 1982).

2.4 Present-day climate

The present-day climate of southern Alberta is cool boreal with a semi-arid soil moisture regime (Clayton et al. 1977a). This area is affected by the Pacific air mass virtually year-round. It is this air mass that is responsible for the numerous chinooks felt in southern Alberta. Warm, dry chinook winds result when Pacific air descends eastern slopes of the Rocky Mountains (Vance 1986). Peak gusts of these west southwest (Beaty 1975a) chinook winds can reach speeds of up to 170 km/h, whereas the average annual wind speed taken at the Lethbridge airport at a height of 10 m is 20.5 km/h (Grace and Hobbs 1986). These winds can result in the temperature rising by 20°C or more during the winter. The prevailing wind direction throughout the year is west. These prevailing winds as well as chinook conditions are associated with low atmospheric pressures. The summer months of July, August and September have the highest monthly barometric pressure and thus are the calmest. High winds can cause soil erosion and can damage crops in the spring. During the spring, they may induce early plant growth which may then be affected by frost (Grace and Hobbs 1986).

2.4a Precipitation Adequate precipitation is critical for agriculture in southern Alberta, because high winds result in high evaporation rates. The two main sources of precipitation are the moist Pacific air which moves east, and the large, warm, moist Gulf air masses moving north. If these air masses meet cold arctic air, significant amounts of precipitation may be produced. The total amount of precipitation in the Lethbridge area varies from year to year with extremes ranging from 194 mm (in 1918) to 709 mm (in 1902), while the average annual is 404 mm (Grace and Hobbs 1986). Precipitation comes in both the form of rain (67%) and snow (33%), with the peak precipitation occurring mainly as rain during the spring. Seventy percent of the total precipitation occurs between April 1 and September 30, with 32% of this occurring during the critical growing months of May and June (Grace and Hobbs 1986). The average annual snow fall at Lethbridge is 141 cm; however, it is rare to have more than 25 cm of snow accumulation since the chinook winds are frequent. The mean monthly temperatures for the year range from -31.5°C to $+18.1^{\circ}\text{C}$, although extreme daily temperature variations, from 15°C to 44°C , are quite common (Grace and Hobbs 1986).

2.4b Climatic history Pollen records provide some indication of the postglacial climatic history of southern Alberta. The early-postglacial vegetation indicates that the

climate immediately following deglaciation was probably cool and relatively dry. The arrival of grasses and sedges signifies a possible change in the climate, although it is unclear whether the climate at this time was indicative of tundra-like conditions or of a grassland environment. The decline in these species appears to correspond with a climatic maximum when warmer and drier conditions than exist today occurred. The AGCM's suggestion that, during this period, precipitation increased is supported by the paleohydrological evidence of filling of basins. This increase in precipitation was accompanied by an even greater increase in evaporation, resulting in drier than present conditions. This period is referred to by many workers as the Hypsithermal and is thought to have occurred at approximately 9 - 7 ka (MacDonald 1987). After this period, climatic conditions appear to have cooled slightly, resulting in a decrease in evaporation and, by around 3 ka, modern climatic conditions were in place (Vance 1986).

2.5 Soils

The dominant soils in the Lethbridge area are classified as Orthic Dark Brown Chernozemic, by the CanSIS inventory system (Clayton *et al.* 1977b). The soil type in the Kipp site is the Lethbridge-Readymade soil, while the soil type found in the other study sites is the Lethbridge soil (Kocaoglu and Pettapiece 1980).

2.5a Chernozemic soils

Chernozemic soils are grassland soils and can be distinguished from other soils mainly by the presence of a dark-coloured A horizon at least 10 cm thick, which experiences a mean annual temperature of 0°C or higher. The four great groups within the Chernozemic order are distinguished on the basis of soil colour, which is a reflection of the amount and pigmentation of soil organic matter (Table 2.2). These soils usually occur under semiarid or subhumid climatic conditions.

Chernozemic soils are distinguished from Brunisolic soils. The latter are forest soils which may contain a dark-coloured surface horizon but have a mean annual temperature below 0°C (Agric. Can. Ex. Comm. Soil Survey 1987). Brunisols have dark-coloured, mineral-organic surface horizons which distinguish them from other soils. Chernozemic soils are also differentiated from Regosolic soils, which do not contain an A horizon. Brunisolic soils have developed enough to exclude them from the Regosolic order, but they lack the horizon development specified for the other orders (Agric. Can. Expert Comm. 1987).

The soils in this study are grassland soils and contain a thick Chernozemic A horizon with a mean annual temperature of approximately 6°C, measured at a depth of 5 cm at the

Chernozemic Order				
	Brown	Dark Brown	Black	Dark Gray
Colour value (dry)	4.5-5.5	3.5-4.5	<3.5	<4.5
Chroma	>1.5	>1.5	1.5 or less	<1.5
Climate	subarid to semiarid	semiarid	semiarid to continental interior	semiarid to continental interior

Table 2.2 Chernozemic order. Colour, Chroma and Climate
(after Agric. Can. Expert Comm. 1987).

Lethbridge Research Station (Grace and Hobbs 1986). The soils in this study are thus designated Chernozemic soils.

2.5b Dating of soils Once a soil has been identified, it is helpful to determine its date of formation to allow a chronological sequence of events to be determined. Several possible methods exist, including carbon 14 dating of materials such as wood, charcoal, peat and extracted fractions of soil organic matter (Evans 1985). However, wood and charcoal are not always reliable indicators due to their susceptibility to transport and contamination by organic compounds (Evans 1985). Carbon 14 dating of opal phytoliths has also been explored (Wilding 1967); however, the large amounts of sample required to retrieve a small amount of phytoliths makes this method impractical. Amino acid racemization dating is also possible if fossils are present in the soil (Rutter et al. 1985). Only a small amount of specimen is needed, although contamination is often a problem and racemization is dependent on temperature, which would vary greatly on the prairies. Barendregt (1985) has used paleomagnetism in stratigraphical studies to determine relative ages of strata and absolute dates of deposits. However, in the absence of suitable dateable material, other methods must be implemented.

Vreeken (1984b) discusses the method of relative dating

of soils and paleosols. This method involves reconstructing the conditions and processes that acted on a soil to determine soil age and genesis. The Principle of Superposition, soil properties, pedogenic indices and soil-landscapes all can be examined to determine relative and absolute ages of soils and paleosols (Vreken 1984b). Dating of soils will be addressed further in Chapter six in the discussion of the soils which developed in the loess deposits.

2.6 Summary

The environmental history of the Lethbridge area for the purposes of this study includes a time period spanning the last 13 000 years. Sometime around 13 ka, the Laurentide and Cordilleran ice sheets retreated from the Lethbridge area. The glacial lakes that were dammed by the retreating ice drained sometime prior to 11.2 ka. The lack of a paleosol directly above the glaciolacustrine silt and clay rhythmites, which were deposited in these glacial lakes, would seem to indicate that drainage of these lakes did not occur much before this time. Immediately following deglaciation of the Lethbridge area, loess began to accumulate.

The vegetation history of this area, based on the pollen records of central and southwestern Alberta seems to suggest that the vegetation species which initially populated this area may have included bryophytes, such as mosses, and

herbaceous plants. These species were likely followed by sedges and grasses, possibly with some willow and alder. At present, it is unclear whether this assemblage is indicative of a tundra or early grassland environment. With slightly moister conditions, this assemblage declined and was possibly replaced by a pine and birch dominated assemblage, followed by spruce sometime around 10 000 BP. Following this period, conditions became drier, indicated by shallower lakes, possibly representing the onset of the Hypsithermal ca. 9000 BP. Sometime around 8000 BP, these warmer, drier conditions appear to have been replaced by cooler and slightly more moist conditions instituting a decline in pine and spruce species and resulting in an increase in birch and grasses. By 3000 BP, conditions similar to modern vegetation and climatic conditions were in place.

CHAPTER 3

METHODS OF STUDY

3.1 Field methods

Observations on sediments and soils, and on their stratigraphic relationships were collected from outcrops and from borehole materials. Fresh outcrops of Quaternary sediments are more commonly found in the vicinity of irrigation return flow ditches where washouts from ditch failures often result in spectacular cliffs and useful sediment exposures. Therefore, this latter type of site was systematically investigated during reconnaissance work. There are also numerous natural outcrops along the Oldman River that are kept fresh by recurrent earthfalls in response to fluvial undercutting of the valley walls. However, since the uppermost parts of these outcrops tend to have slumped materials, overgrown by vegetation, these outcrops are generally more suitable for the study of bedrock geology, which is only of incidental importance to the present research.

Sediment cores were taken using a trailer-mounted Giddings hydraulic coring machine with 5 cm and 3.15 cm inside diameter coring tubes. Provided that the moisture contents of the sediment are below the plastic limit, which is commonly

the case during the summer, these cores display virtually undisturbed fabrics and useful information. Borehole sites utilized during reconnaissance were located from topographic maps. In addition, those cored subsites that formed part of transect work were surveyed by theodolite.

The outcrops and cores were described in the field using standardized criteria (Soil Survey Staff 1951). Bulk samples were collected observing sedimentary and stratigraphic boundaries and soil horizons. The maximum thickness of sample increments was maintained at 15 cm.

3.2 Laboratory methods

3.2a Grain size composition and volcanic glass Grain size composition was determined using the pipette method described by Kilmer and Alexander (1949). This entails sample pretreatment with acetic acid which serves to inhibit rapid consumption of peroxide by manganese compounds, followed by the addition of hydrogen peroxide to oxidize and destroy aggregate-building organic constituents. Calgon was used as a chemical dispersant with twice the prescribed dosage to overcome the flocculating effect of neutral salts which are common to earth materials in this region. Sand fractions were determined by wet-sieving. When calculating grain-size composition, no correction was made for any loss of organics or other soil constituents during pretreatment. As a

consequence, any errors attributable to this are accumulated in the values assigned to the very coarse silt fraction (62-31 μm). The very fine sand (125-62 μm) fractions were routinely examined for the presence of volcanic glass. Glass counts were done by examining 200 grains in a loose boustrophedon pattern.

3.2b Organic and inorganic carbon Organic and inorganic carbon contents were determined using a Leco induction furnace with carbon analyzer (McKeague 1978). Induction analysis was done using tin as the fluxing material and iron chips as the accelerator. The total carbon content of most samples included organic as well as carbonate carbon. To determine the organic carbon content, additional samples were treated with hydrochloric acid (3N) to digest carbonates after which the samples were dried on a hot plate and assayed by the Leco method. The samples were then burned to determine organic and total carbon content. Inorganic carbon content, the difference between total and organic carbon content, was reported in terms of the equivalent percentage of calcium carbonate.

3.2c pH The pH of the samples was determined using a Fisher Accumet 380 pH meter using a dilution of 1 part of soil to 2 parts of distilled water (McKeague 1978).

CHAPTER 4

RECONNAISSANCE WORK

Reconnaissance was undertaken to gain sufficient familiarity with the variability of the terrain and subsurface of the Lethbridge area to select a site for more detailed study. The main consideration that influenced the selection of this site was that it would have to be underlain by relatively thick and stratigraphically diversified loess. Furthermore, the presence of buried soils and dateable materials, such as tephra beds and fossil wood, peat, shells, or bone would constitute major assets. Equally important was the accessibility of terrain to coring and trenching machinery, to be used in unravelling the three-dimensional subsurface variability.

Deep exposures in this area are essentially restricted to the valley of the Oldman River and its major tributaries. This explains, in part, the general distribution of reconnaissance sites in Figure 2.4 and Table 4.1. An additional explanation is the following: cursory examinations of road cuts throughout the area revealed that loess is either thin or absent well away from the river valley, so that exposures of relatively thick loess are most probably distributed along the periphery of the upland.

Study Site	Location	Elevation (asl)	Max. Loess Thickness	Owner
Glacial Lake MacLeod Plain				
Kipp Site UL589 100	1sd 9, sec.18, tp. 9, rge. 22 W 4th mer. (49 44'N, 112 57' W)	935m	6.7m	Animal Diseases Research Institute
C&P Crushing Site UL562 135	1sd. 6, sec.24 tp. 9, rge.23 (49 46'N, 113 00'W)	890m	4.0m	C&P Crushing
Glacial Lake Lethbridge Plain				
Barrons Site UL701 223	1sd.14, sec.21 tp.10, rge. 21 (49 50'N, 112 48'W)	890m	3.0m	Mr. John Barrons
Van der Heyden Site UL722 222	1sd. 4, sec.22 tp.10, rge. 21 (49 50'N, 112 48'W)	884m	2.5m	Mr. John Van der Heyden
Diamond City UL664 222	1sd. 2, sec.1 tp. 9, rge.22 (49 47'N, 112 51'W)	907m	1.8m	L.N.I.D.
Popson Park UL666 012	1sd.12, sec.13 tp. 8, rge.22 (49 38'N, 112 51'W)	930m	2.8m	City of Lethbridge
Airport Site UL710 013	1sd. 15, sec.3 tp. 8, rge. 21 (49 38'N, 112 47'W)	910m	3.7m	Mr. C. Stewart

Table 4.1 Location of study sites.

During evaluation, it transpired that almost all reconnaissance sites revealed useful information. Ultimately, the Kipp site, on the lake plain of Glacial Lake MacLeod, was selected as the primary study site because it had the most interesting geomorphic setting, optimal accessibility, and excellent tenant cooperation. Preliminary observations on the Kipp site are excluded from this chapter.

4.1 Van der Heyden site

4.1a Location and setting The Van der Heyden site (Figures 2.4 and 4.1, Table 4.1) is located 3.8 km south of the town of Picture Butte, on the plain of Glacial Lake Lethbridge. The site contains a 20 m deep and 75 m long ravine that extends northward from a tributary coulee of the Oldman River which is located 1.2 km east of the ravine. Vreeken (1989) reported cursory observations on the ravine exposure. The site also includes a smaller side gully approximately 3 m deep which extends southeastwards from the main ravine.

4.1b Stratigraphy

Three major stratigraphic units are exposed along the ravine. The basal unit, about 15 m of massive diamicton, is overlain by a 1 m thick complex of silt and clay rhythmites, which is overlain by a loam complex (Figure 4.1). The rhythmite complex includes a diamictic interbed and it has

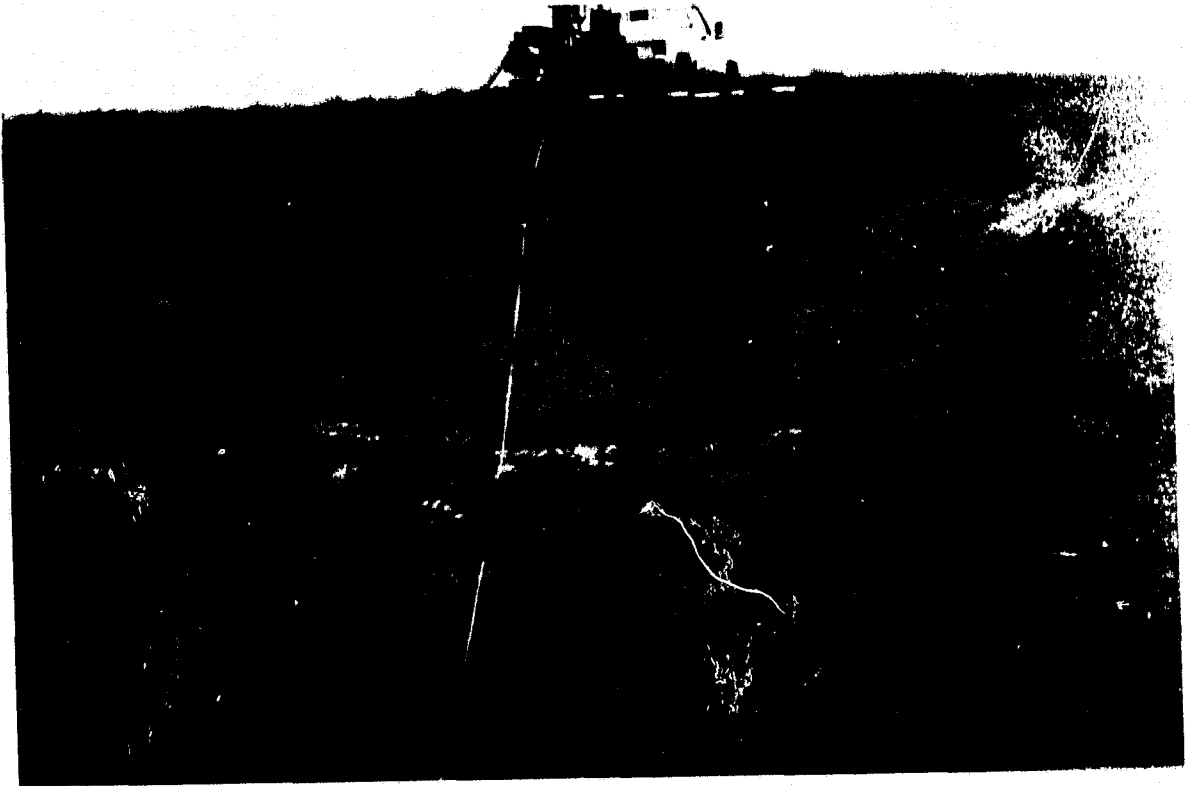


Figure 4.1 The Van der Heyden site located 3.8 km south of the town of Picture Butte. The yellowish brown basal unit is massive glacial diamicton, interpreted as till (A). This is overlain by glaciolacustrine rhythmites composed of alternating light grey silt and brown clay layers (B), with a diamictic interbed (C). Capping the rhythmites is a yellowish brown loess complex (D), containing several greyish brown buried soils. The prominent dark stained zone (E) was developed from silt loam loess and it is overlain by sandy loam loess.

been weakly deformed. It drapes the bottom of a broad 1.5 m deep depression in the top of the basal diamicton. In places, a thin (2.5 cm) stone line occurs at the top of the diamicton interbed. The loam complex is up to 3.5 m thick. It fills the remainder of the depression and it has a level surface.

The loam complex is divided into a lower and an upper part (Figure 4.1). The lower loam is a yellowish brown, massive, calcareous silt loam with, near the base, a thin (1 cm), planar, distinct white, silty tephra bed, which was traced for a distance of ten metres along the ravine wall. This silt loam unit directly overlies the silt and clay rhythmites and its top is marked by a prominent dark-stained zone (approximately 0.6 m thick) which includes several grey brown buried soils. It is up to 1.4 m thick and it is mainly confined to the depression on the basal diamicton. The upper loam unit is a yellowish brown, calcareous sandy loam, up to 2.4 m thick and it extends, along the ravine exposure, well beyond the confines of the basal depression and beyond the lower silt unit. The basal portion of the sandy loam unit contains the second tephra bed at this site. Its upper portion includes several grey brown buried soils, apart from the surface soil.

A borehole was made about 3 m away from the wall of the ravine to obtain direct observations on materials exposed

along the inaccessible ravine wall (Figure 4.1). It revealed 2.5 m of sandy loam over 1.0 m of silt loam. Scattered tephra grains were located, from microscope analysis, between 312 and 310 cm and between 240 and 222 cm depth, respectively. The borehole description is in Appendix A.

The side gully that extends away from the ravine is up to 3 m deep. It displays the silt and clay rhythmites and a 2 m thick loam mantle. This mantle again consists of a lower, silt loam unit and an upper, sandy loam unit.

4.1bi Interpretation The basal diamicton unit has been traced from this site in outcrops along the Oldman River valley and from there, along a tributary coulee into the Lethbridge moraine (Vreeken, 1989). It therefore represents the youngest glacial till in the area and it dates to the Late Wisconsin. The broad depression at the top (Figure 4.1) is probably a subsidence feature that may have been formed when ice that was contained in the till melted away. The overlying silt and clay rhythmites with the diamictic interbed are glaciolacustrine sediments that accumulated in Glacial Lake Lethbridge. The diamictic interbed may represent a debris flow deposit composed of gravitationally reworked material originating from an adjacent portion of the basal diamicton unit. Its presence within the rhythmite sequence suggests that mass movement along the lake bed, into subsidence

hollows, occurred before the basal diamicton had become consolidated. The loam complex overlying the glaciolacustrine sediments is of aeolian origin and can be called a loess complex. Its aeolian origin is inferred from its massiveness, from its loamy nature, from its distribution across the highest landscape in the area, and from the presence of numerous paleosols within it. Vreeken (1989) equated the two tephra beds within the loess with 11.2 ka Glacier Peak tephra and 6.8 ka Mazama tephra that were identified from a similar sequence at the Barion site (section 4.2). Application of these age values to the drill core suggests that the average rate of loess accumulation was 0.18 mm/a between 11.2 and 6.8 ka, and that it was 0.35 mm/a since 6.8 ka. These rate estimates do not make allowance for erosional or depositional hiatuses within the loess complex.

4.1c Summary The Van der Heyden site contains Late Wisconsinan till beneath Glacial Lake Lethbridge sediments. The glaciolacustrine sediments do not have a paleosol developed in their top part. This suggests that loess accumulation began immediately following drainage of the glacial lake. The presence of numerous buried soils within the loess complex indicates that loess accumulation was a cyclic phenomenon, and the presence of tephra beds indicates that loess accumulated during much of the last 11 000 years, at this site. During this interval, the depression on the

former lake bed was entirely obliterated from the landscape. The difference in grain-size composition between the lower and the upper loess suggests that they originated from different loess dispersal systems.

4.2 Barron site

4.2a Location and Setting The Barron site (Figures 2.4 and 4.2, Table 4.1) is 4 km southwest of the town of Picture Butte, on the generally level lake plain of Glacial Lake Lethbridge. It includes a 25 m deep, 75 m long ravine that extends northwards from Piyami Coulee, a tributary to the Oldman River which is located 3.5 km east of the ravine. This site was described by Vreeken (1989).

4.2b Stratigraphy

The ravine exposure reveals a basal unit of massive diamicton, about 20 m thick, overlain by a strongly deformed complex of silt and clay rhythmites with thin diamictic interbeds (Figure 4.3). This is overlain by a loam complex. The complex of rhythmites has been folded into the subjacent massive diamicton and it is thickest beneath a depression in the former lake bed. The loam complex is thickest, up to 3 m, above this depression, where it forms a low mound. It is divided into a lower, a middle, and an upper unit (Vreeken, 1989). The lower loam unit rests directly on the deformed

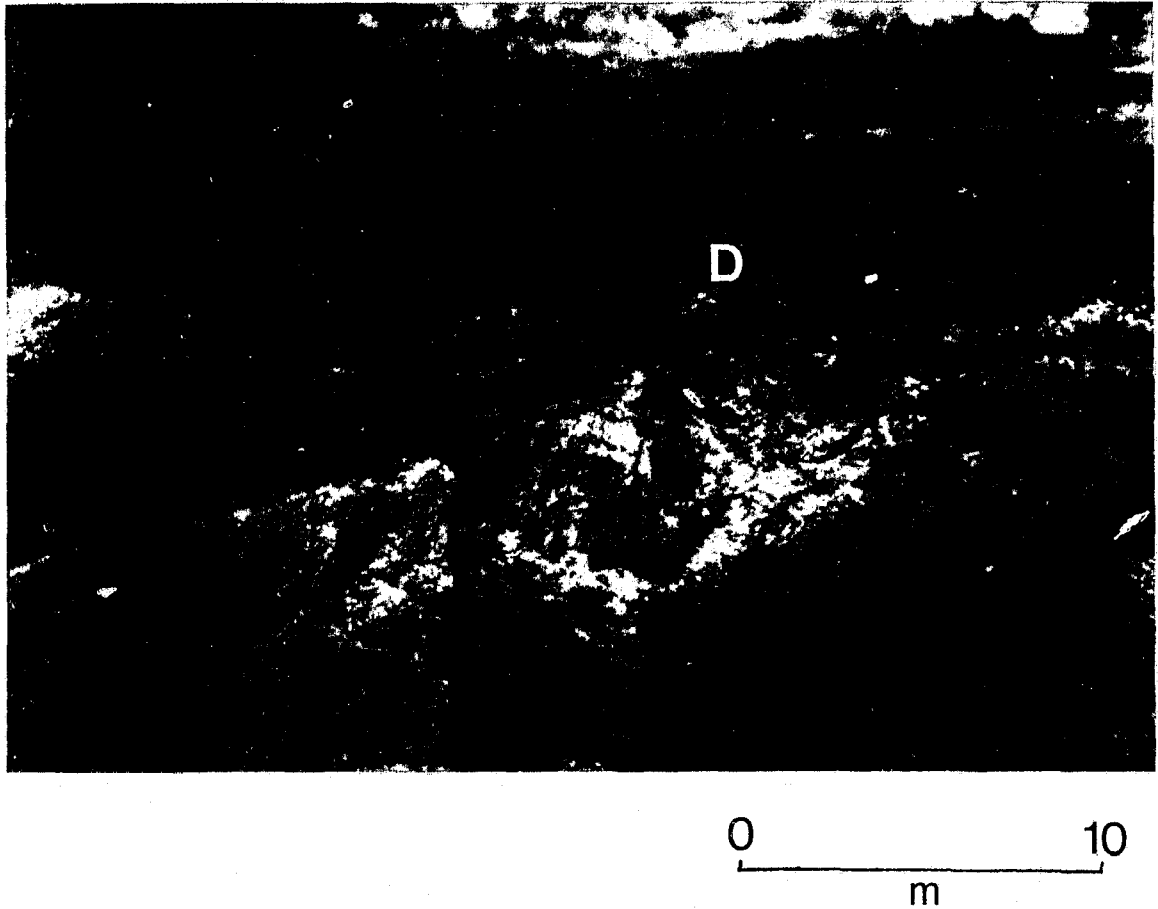


Figure 4.2. The Barron site located 4 km southwest of the town of Picture Butte. The basal unit is massive glacial diamicton (A), overlain by a complex of silt and clay rhythmites (B) with thin diamictic interbeds. This is overlain by a loess complex (C) containing several buried soils. The prominent dark stained zone (D) within the loess is a composite of several welded buried soils. The thin pale band above that dark stained zone is a Mazama tephra bed (E).

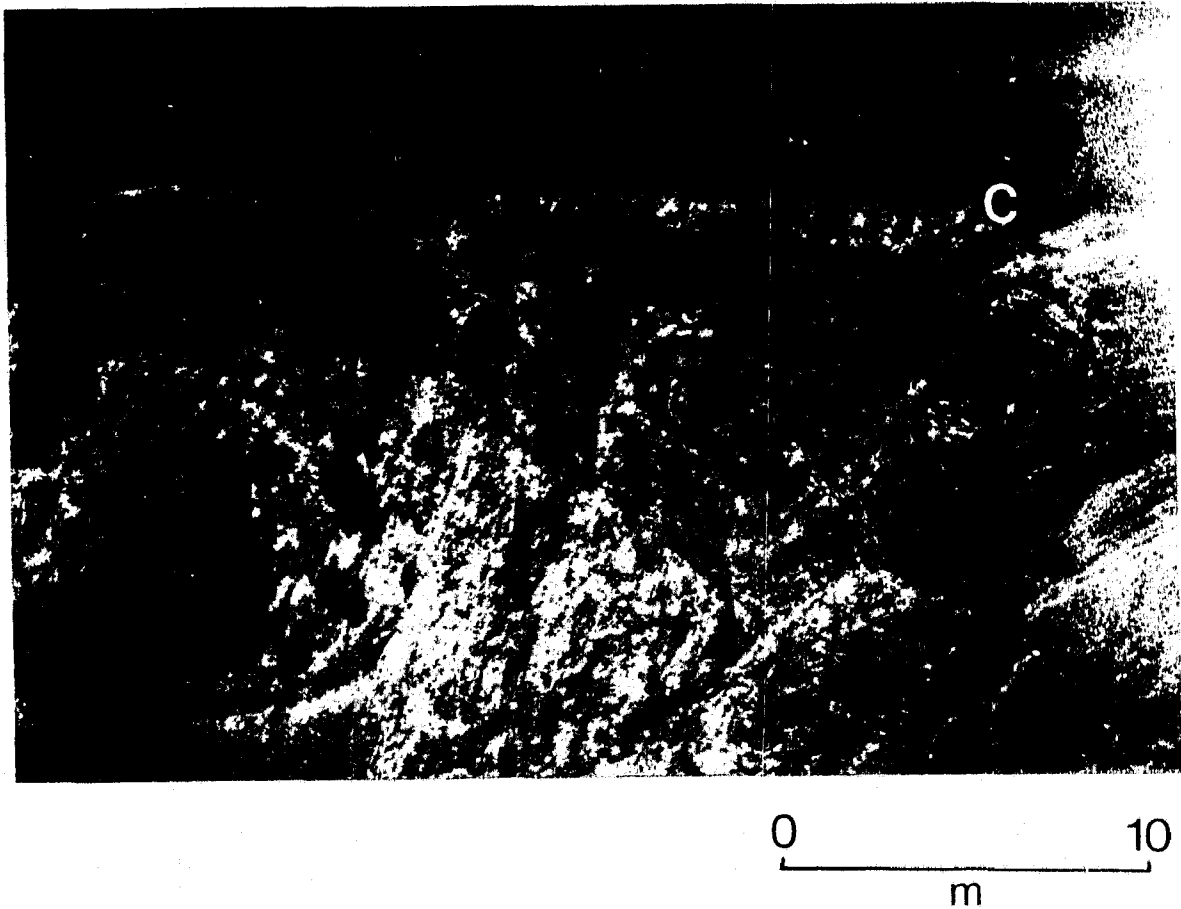


Figure 4.3. The southern end of the ravine at the Barron site shows strongly deformed glaciolacustrine silt and clay rhythmites (B), above massive glacial diamicton (A). The dark stained zone (C) that marks the top of the lower loess, on the right side of the photograph, is seen to thin away towards the left (south).

rhythmites. It is a yellowish brown, calcareous silt loam with a thin (1 cm), white, planar, silty tephra bed, 30 cm above the base and with greyish brown buried soils in the upper part of the unit, that are welded together into a prominent dark stained zone (Figure 4.2). This zone thins away into oblivion to the left (south) of the exposure (Figure 4.3). This lower loam unit is mainly confined to a depression on the glaciolacustrine substrate. The middle loam, a yellowish brown calcareous sandy loam, directly overlies the silt loam unit in a continuous horizontal layer extending beyond the boundaries of the lower silt unit. It contains a second, 0.25 m thick, light grey tephra bed at its base that extends for approximately 70 m along the exposure, beyond the boundaries of the lower silt. This middle unit contains several brownish grey buried soils and its top is marked by a more prominent dark zone composed of three welded paleosols. The middle unit extends beyond the lower loam unit, to the right (north). The upper loam unit is a yellowish brown calcareous sandy loam with two buried soils, apart from the surface soil. The upper loam unit is continuous along the exposure and it directly overlies the middle loam unit. Whereas the lower loam fills the broad depression on the substrate, the middle and upper loam units form a distinct mound that extends beyond the lower loam.

4.2bi Interpretation The basal diamicton unit at this site can be traced westwards, along Piyami Coulee, into the Lethbridge moraine, where it terminates. It is a glacial till. The overlying silt and clay rhythmites are regarded as glaciolacustrine sediments that accumulated in Glacial Lake Lethbridge. They occupy a depression in the basal diamicton that is interpreted to be a result of syndepositional soft sediment deformation. These sediments are thickest where they are most deformed (Figure 4.3). Rhythmite material likely slid in from the sides into a depression in the top of the main diamicton. In response to this loading, the diamicton appears to have been pushed up around the perimeter of the depression probably while it was in a very soft and plastic state. This process likely occurred before lacustrine sedimentation had altogether ceased. The initial depression in the top of the diamicton likely resulted from ice melting within the diamicton which may have created subsidence channels which the rhythmite materials slumped into. The relationship of the deformed glaciolacustrine rhythmites to the underlying basal diamicton indicates that till deposition, deglaciation of the Lethbridge moraine and commencement of sedimentation in Glacial Lake Lethbridge all occurred within a relatively short period of time (Vreeken 1989).

The loam complex, with the paleosols and the two tephra beds, that overlies the glaciolacustrine rhythmites, is

aeolian in origin and consists of loess. This is inferred from the facts that it extends beyond the confines of the basal depression and that it forms a mound which constitutes the highest land in the local landscape. This mound-forming material can only have been supplied by the wind. Using results from electron microprobe analysis, Vreeken (1989) identified the lower tephra bed as Glacier Peak layer G which was ejected approximately 11.2 ka (Mehring et al. 1984). The uppermost tephra bed is Mazama ash (Vreeken 1989), ejected about 6.8 ka (Bacon 1983). From these age values and from thickness measurements, it is calculated that the average loess accumulation was 0.41 mm/a between 11.2 and 6.8 ka, and 0.25 mm/a since 6.8 ka. The thicknesses used were measured at a point on the ravine wall opposite to the one shown in Figure 4.2, where all loess units are represented. Earlier, Vreeken (1989) inferred also, from the absence of paleosolic imprints beneath and just above the Glacier Peak tephra bed, that rates of loess accumulation were initially much higher than subsequently.

At the south end of the ravine, the paleosolic complex at the top of the lower loess unit has been truncated by erosion (Figure 4.3). This probably entailed deflation prior to accumulation of the middle loess unit. At some time between the two volcanic eruptions the loess dispersal system changed, as is evident from the differences in grain-size composition

between the lower, silt loam loess and the overlying, more sandy loess of the middle and upper units.

The change from silt-loam to sandy loam loess in this sequence is unknown. However, if the rates of accumulation calculated from the tephra beds are considered, then an approximate date for the change from the lower silt dominated loess to the more sandy loess can be determined. The depth at which the change from silt loess to sandy loess occurs is approximately 2.45 metres. If the rate of 0.41 mm/a is used to determine a date for this depth, then an average date of approximately 9 ka results. If the rate of 0.25 mm/a were used, a date of approximately 9.6 ka is calculated. It is therefore possible that the change from the silt dominated lower loess to the more sandy middle and upper loess may have occurred between approximately 9 to 9.6 ka.

4.2c Summary The Barron site reveals till that can be traced to the Lethbridge moraine. Glaciolacustrine silt and clay rhythmites mantle the surface of this till and are highly deformed as a result of soft sediment deformation, attributed to the melting out of ice that may have been contained within the diamicton and to the simultaneous loading of lake sediments, before consolidation of the sequence. The overlying loess complex contains three loess units differentiated by texture. These aeolian sediments are dated

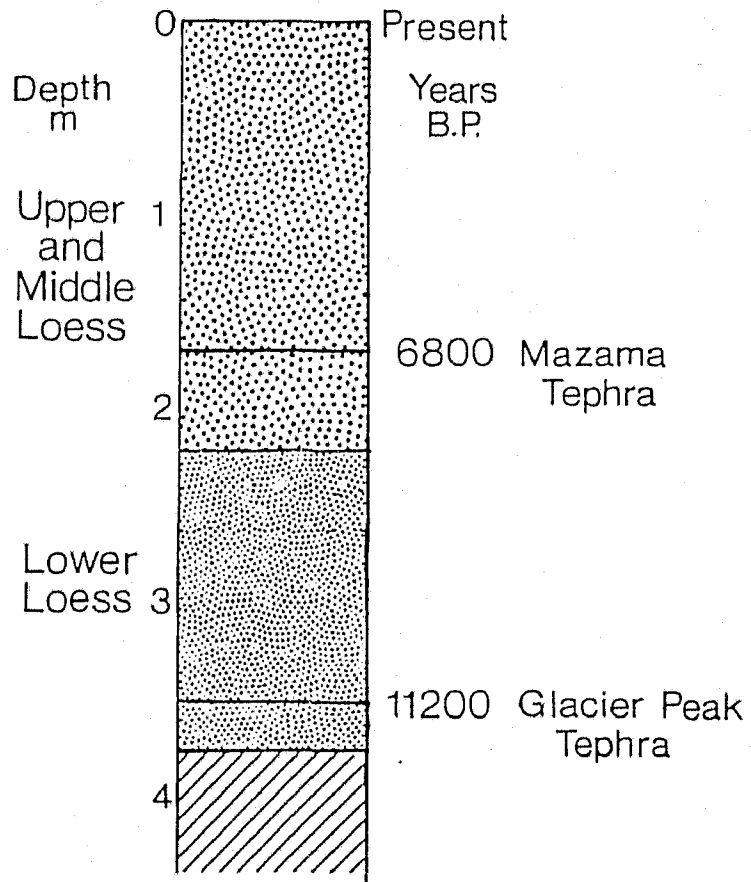


Figure 4.4. Mazama and Glacier Peak tephra at the Barron site allow for calculation of average rates of accumulation between 11.2 and 6.8 ka and since 6.8 ka (Table 4.2). Accordingly, the shift from silt loam to sandy loam loess which is marked at a depth of about 2.45 m may have occurred between approximately 9 and 9.6 ka.

by two tephra beds, Glacier Peak tephra (ca. 11.2 ka) and Mazama tephra (ca. 6.8 ka) and average rates of accumulation calculated on the basis of these two tephra beds indicate that initially the rate of accumulation was probably much higher than subsequently, and the change in the dispersal system from a silt loam to a sandy loam may have occurred between approximately 9 and 9.6 ka.

4.3 Diamond City Site

4.3a Location and Setting The Diamond City site (Figures 2.4 and 4.5, Table 4.1) is located 1.5 km southwest of the town of Diamond City, on the lake plain of Glacial Lake Lethbridge. This site encompasses an area of about 80 ha that is typified by ravines with depths ranging from 5 to 20 m. These ravines extend southeast to a tributary coulee of the Oldman River, which is located 1.5 km farther southeast.

4.3b Stratigraphy

A section located on the northern side of the site, parallel to Highway #25 contains 20 m of massive diamicton, overlain by a 0.5 m thick unit of silt and clay rhythmites, that is capped by loam. The diamicton is a gritty sandy loam, yellowish brown with massive structure and with a few scattered pebbles and stones. The silt and clay rhythmites are weakly deformed and mantle the surface of the basal diamicton. Figure 4.5 illustrates a pronounced depression in

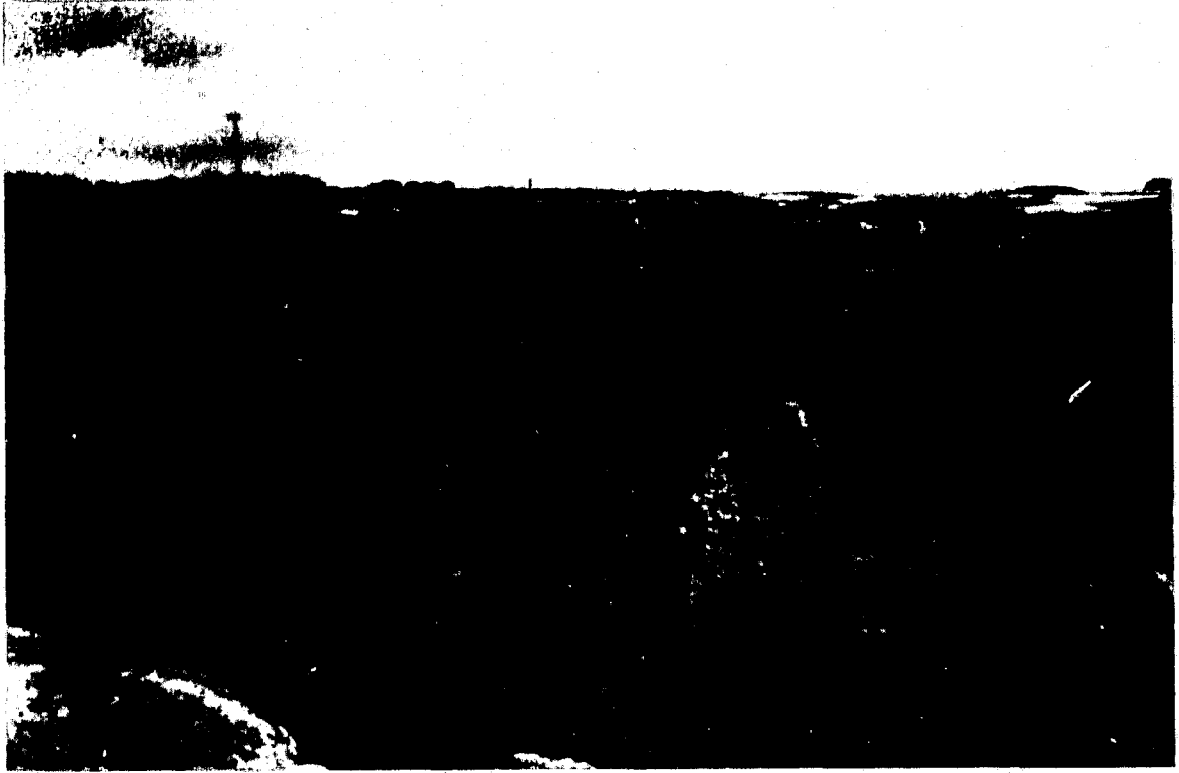


Figure 4.5. The Diamond City site located 1.5 km southwest of the town of Diamond City. This view facing west shows massive yellowish brown diamicton (A), overlain by a unit of silt and clay rhythmites (B) that is capped by loess (C). The rhythmites and overlying loam complex fill a broad depression (indicated by the dashed line) in the top of the diamicton.

the top of the diamicton, largely filled with rhythmite materials. The loam unit is up to 1.5 m thick, and it consists of yellowish brown calcareous loam. No buried soils were noted beneath or just above the base of the unit. Instead, a thin, up to 0.5 cm thick, white, silty tephra bed was found 30 cm above the base of the loam.

4.3bi Interpretation The basal diamicton unit at this site is interpreted to be glacial till because it is traceable along the Oldman River valley to the Barron and Van der Heyden sites. Similarly, the overlying silt and clay rhythmites are interpreted as sediments deposited in Glacial Lake Lethbridge, whereas the mantling loam is regarded as loess. The tephra bed is likely Glacier Peak tephra ca. 11.2 ka, in view of its colour, thickness and stratigraphic position, which are similar to those for the lower tephra bed at the Barron site.

4.3c Summary The Diamond City site reveals glacial till, glaciolacustrine silt and clay rhythmites that were likely deposited in Glacial Lake Lethbridge, and a thin loess cover. The tephra bed within the loess probably represents Glacier Peak tephra, circa 11.2 ka old. The rhythmites and overlying loam complex fill a broad depression in the top of the diamicton.

4.4 Popson Park Site

4.4a Location and Setting The Popson Park site (Figures 2.4 and 4.6, Table 4.1) is located 3.3 km south of the west side of the city of Lethbridge in Popson Park, on the lake bed of Glacial Lake Lethbridge. It is on the upland directly along the Oldman River, which is located 350 m south. This cut is approximately 5 m deep and 15 m long.

4.4b Stratigraphy

The basal units at this site consist of massive diamicton overlain by silt and clay rhythmites, with few scattered stones and cobbles and with large (2-4 cm) reddish-brown oxidation stains in the matrix material. This is overlain by a bipartite loam complex. The lower subunit up to 0.4 m thick, is an olive brown, calcareous silt loam, with few clay nodules about 1 cm thick. It has a prominent dark paleosolic A horizon developed in its upper 30 cm. The upper subunit is a yellowish brown calcareous sandy loam, up to 2.5 m thick and it has a strongly developed surface soil developed from it.

4.4bi Interpretation The silt and clay rhythmites at this site are interpreted as glaciolacustrine rhythmites that were deposited in Glacial Lake Lethbridge. The randomly oriented stones and cobbles in it are probably dropstones which were rafted in by floating ice. The overlying loam is interpreted as loess, by virtue of its

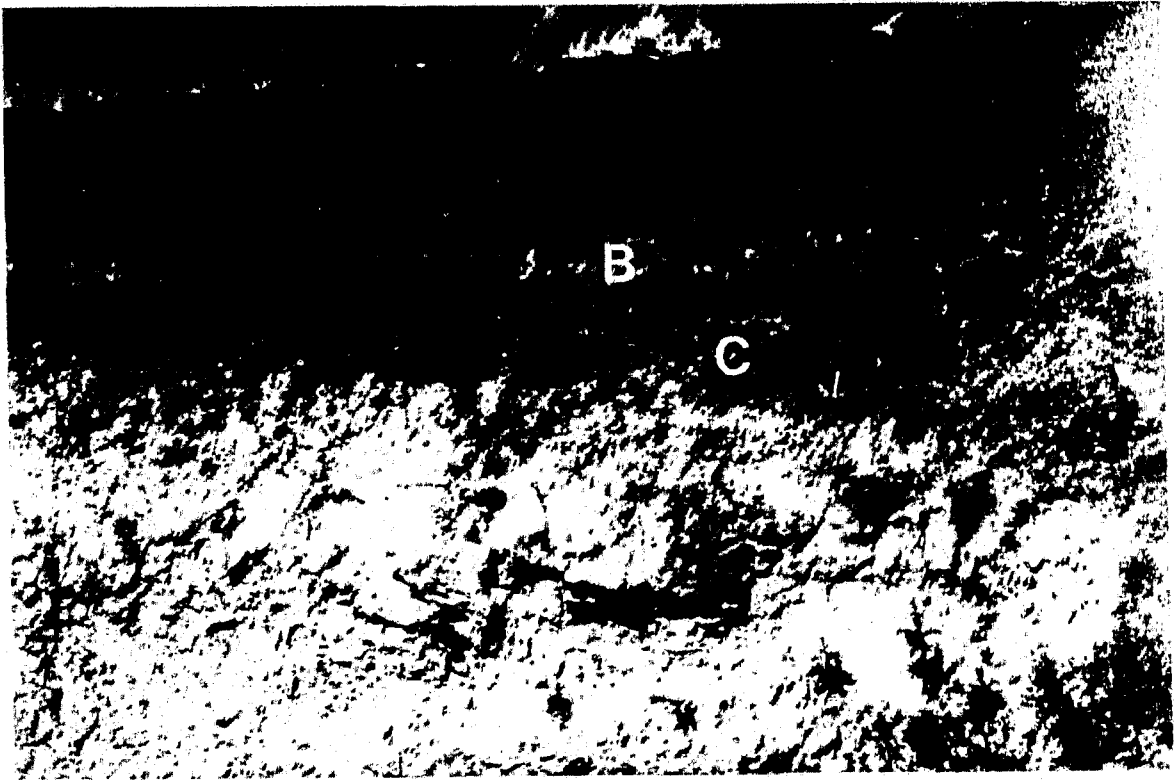


Figure 4.6. Popson Park site located 3.3 km south of the west side of the city of Lethbridge in Popson Park. This site has silt and clay rhythmites (A), overlain by loess (B) that contains one dark paleosol (C). The knife 25 cm long is positioned 20 cm below the top of this paleosol.

position on the upland and the presence of a buried soil. This loess contains two differently textured units, that are indicative of a shift in the depositional regime.

4.4c Summary The Popson Park site reveals glaciolacustrine silt and clay rhythmites, likely deposited in Glacial Lake Lethbridge, that are capped by a lower silt dominated loess, overlain by an upper sand dominated loess.

4.5 Airport Site

4.5a Location and Setting The Airport site (Figures 2.4 and 4.7, Table 4.1) is located 1.9 km south of the city of Lethbridge, on the lake bed of Glacial Lake Lethbridge. It refers to an exposure, approximately 4 m in depth and 20 m long, along the wall of a coulee that is tributary to the Oldman River, 2.8 km further west. This coulee has been incised about 40 m below the lake plain.

4.5b Stratigraphy

The basal unit exposed at this site consists of diamicton interbedded with sands and silts and overlain by thin (about 10 cm) deformed silt and clay rhythmites. A 30 to 60 cm thick unit of faintly bedded calcareous loam with scattered mollusc shells and several poorly developed pebble bands rests on these. This has a weakly developed soil in its top, overlain by massive sandy loam.

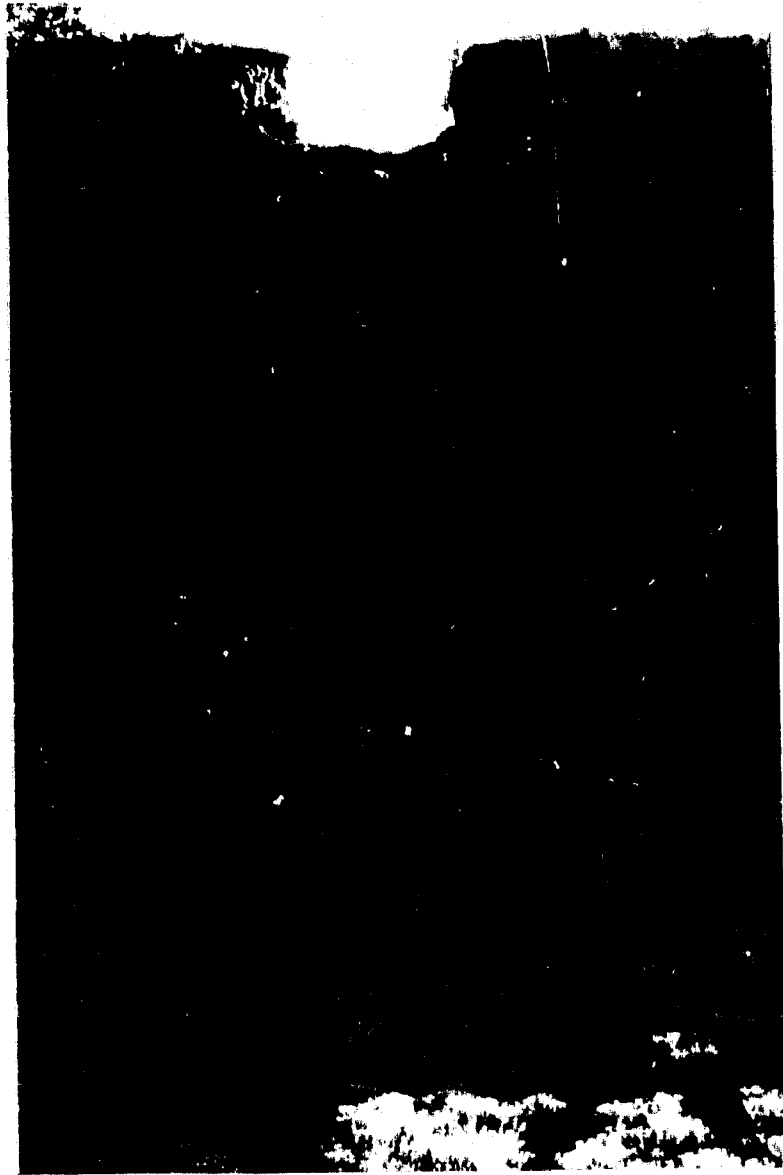


Figure 4.7. The Airport site located 1.9 km south of the city of Lethbridge. This site shows diamicton at the base (A), overlain by a rhythmite unit (B). A fluvial unit (C) containing freshwater shells covers this unit and the entire sequence is capped by a thin loess unit (D). Note the measuring tape at the top-right approximately 60 cm long.

Gastropod species represented by the shells are *Stagnicola elodes* and *Gyraulus parvus*, along with *Gyraulus deflectus*, *Physella jennessi skinner* and *Fossaria bulimoides morph. cockerelli* (J. Dale personal comm.) (see Appendix E).

4.5bi Interpretations The basal unit is glacial diamicton and the silt and clay rhythmites are glaciolacustrine sediments, likely deposited in Glacial Lake Lethbridge. The overlying bedded loam with pebble bands is of fluvial origin, and the shells are from freshwater gastropods. Present-day representatives of the fossil shells, such as still are present in the Prairies, are found in permanently or seasonally wet, muddy and vegetated habitats (Appendix E). These habitats either were shifted to another part of the landscape during stream migration and incision or they disappeared altogether when loess began accumulating at this site. These shells have not been dated. The overlying massive sandy loam is attributed an aeolian origin by virtue of its landscape relationships.

4.5c Summary The Airport site contains glacial till with waterlaid interbeds and overlain by glaciolacustrine silt and clay rhythmites, likely deposited in Glacial Lake Lethbridge. The thin overlying fluvial sediments are mantled by sandy loess.

4.7 C&P Crushing Site

4.7a Location and Setting The C&P Crushing site (Figures 2.4 and 4.8, Table 4.1) is located in the Oldman River Valley 10 km northwest of the city of Lethbridge, and to the west of the Lethbridge moraine. It refers to an erosional remnant within the valley, with a level top that, at 929.6 m asl, is accordant with relicts of the lake plain of Glacial Lake MacLeod on upland surfaces to the north, east, and west of it. The subsite addressed here is at 899.2 m asl, about 30 m below the summit, on the eastern slip off slope of the remnant and about 30 m above the valley bottom of the deeply incised cut off meander loop that surrounds it and which is at 869 m asl. This subsite is a 10 m long and 5 m deep east-west aligned trench that was excavated during exploration for commercial gravel resources.

4.7b Stratigraphy

Exposures along the western slope of this erosional remnant, extending below its level summit, reveal Lenzie silts, overlain by silt and clay deposits that are attributable to Glacial Lake MacLeod, and that are overlain by an unit of loess.

The basal unit in the trench section consists of clast-supported pebbles and cobbles (Figure 4.8). Its upper boundary has swell-swale topography. One of these swales is

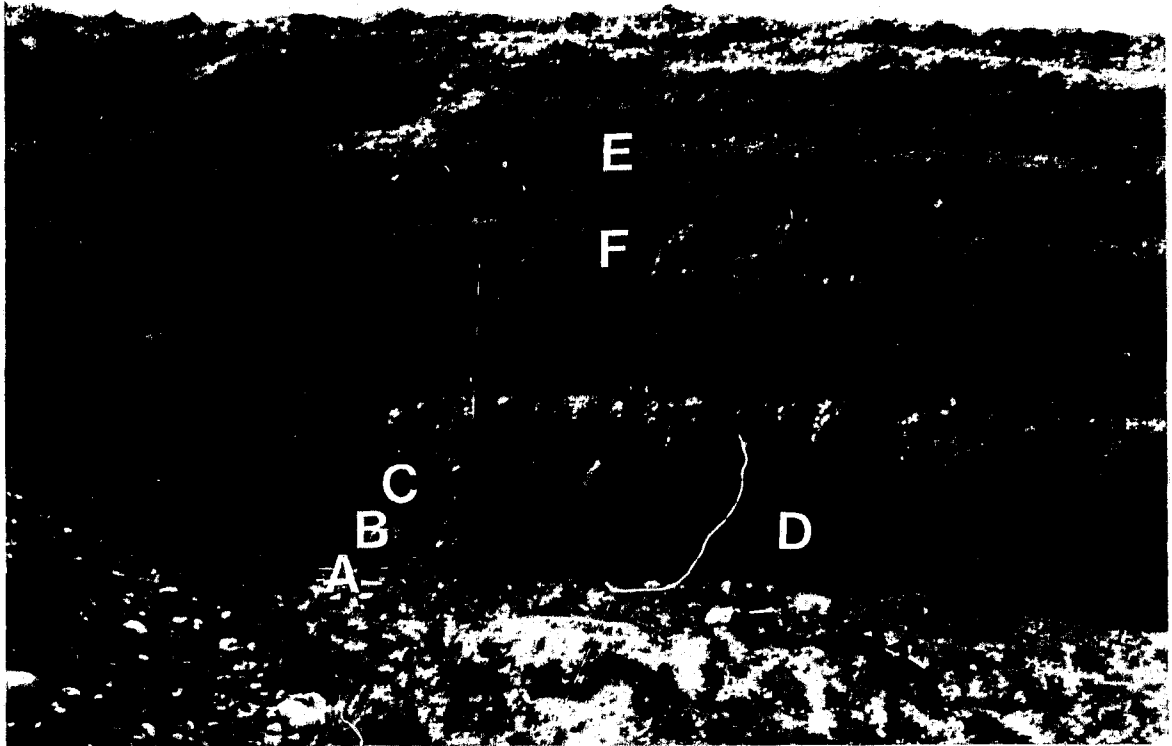


Figure 4.8. The C & P Crushing site located 10 km northwest of the city of Lethbridge, in the Oldman River Valley. This site shows fluvial gravels (A) overlain by a unit of very fine gravel (B), that grades upwards into planar laminated medium sands (C). These sands contain a tephra bed (located below the staff, at D), correlated on the basis of its position with confined Glacier Peak tephra 11.2 ka at the Barron site. This tephra probably dates the position and elevation of the Oldman River immediately following drainage of Glacial Lake MacLeod. This unit is overlain by a loess complex (E), up to 3.5 m thick, containing a second tephra bed (at the top of the staff, at F) correlated with Mazama tephra 6.8 ka. Staff markings are 30 cm increments.

filled by a unit of crossbedded coarse and medium sands, with intercalations of very fine gravel, that grade upward into planar laminated medium sands. Within the latter sands, 35 cm below their upper limit, is a white, planar, silty tephra bed, up to 1 cm thick and traceable over a distance of ten metres. This bed and the sands below and above it dip to the east, i.e. downslope, by about 15 degrees.

The laminated sands grade upwards into a loam complex that rests directly on the adjacent swell on the gravel substrate. The loam sequence includes many weakly developed buried soils and a second tephra bed, up to 10 cm thick. Thickness relations for the loam complex differ from point to point because its base is inclined and its top is subhorizontal, so that intervening sediment wedges thicken eastward, along the exposure. At one point, the loam complex is 3.9 m thick, the increment between the tephra beds being 1.8 m and the unit above the upper tephra bed being 2.0 m thick.

4.7bi Interpretation The basal gravels are interpreted as fluvial gravels and the swells that mark this surface are gravel bars. The overlying crossbedded sands and gravels are also of fluvial origin. The planar laminated sands into which they grade and which contain the tephra bed likely are aeolian sands. This is inferred from their

sedimentary structure and from the preservation of the tephra bed which is dominated by silt-size grains. Such fine-grained material would have been removed, almost certainly, by streamflow capable of transporting the sand-size material within which the silt intercalation occurs now. On the other hand, the tephra deposit would have had a better chance of remaining preserved beneath sand that was supplied by the wind.

The overlying loam unit with the second tephra bed is interpreted as aeolian. It extends to the very top of the erosional remnant. This surface could not have been supplied by fluvial action after cutting of the slip-off slope. Criteria supporting the inference that this loam represents a loess deposit are the absence of fluvial sedimentary structures from this loam and the presence of the many buried soils.

The lower tephra bed likely represents the 11.2 ka Glacier Peak eruption and the upper tephra bed the 6.8 ka Mazama eruption. If so, average rates of loess accumulation at this subsite would have averaged 0.41 mm/a. between 11.2 and 6.8 ka, and 0.29 mm/a, since 6.8 ka.

The slope of the erosional remnant bevels the relict plain of Glacial Lake MacLeod, preserved on top of the

remnant, which simply confirms that this fluvial erosion surface postdates drainage of the former lake. Incipient fluvial incision of that lake plain required fluvial action below 930 m asl which also happens to have been the elevation of the water level of Glacial Lake Lethbridge, set by the elevation of Etzikom Coulee, its former outlet (Horberg 1954). This means that subaerial conditions on and fluvial incision of the lake plain of Glacial Lake MacLeod began only upon drainage of Glacial Lake Lethbridge. Thus, the latter drainage event coincides with the earliest time at which aeolian action on the plain of Lake MacLeod can have started, so that it sets the oldest possible age of aeolian sediment mantling that lake plain. These geomorphic relationships signify that the possible ages of aeolian sediments on both lake plains are essentially the same.

The fluvial erosion surface that is represented by the meander slip-off slope on the erosional remnant covers an elevation range from 929.6 to 869 m asl and formed time-transgressively, from the onset of drainage of Glacial Lake Lethbridge until the time when the meander loop was cut off. The observation that the Glacier Peak (?) tephra bed runs into a fossil fluvial gravel bar at the study subsite (Figure 4.8) at about 895 m asl, signifies that the Oldman River had incised its bed already 35 metres below the plain of Glacial Lake MacLeod, by 11.2 ka, i.e. about 1000 years earlier than

was inferred by Stalker (in Lowden and Blake 1975).

4.7c Summary The C&P Crushing site contains fluvial gravels below a Glacier Peak (?) tephra bed, which if confined would date the position and elevation of the Oldman River immediately following drainage of Glacial Lake MacLeod. The overlying sands document the change from fluvial to aeolian sand deposition. This mantling loess complex contains a Mazama (?) tephra bed and accumulated into recent times. Stream incision below the lake plain of Glacial Lake MacLeod dates to the time when drainage of Glacial Lake Lethbridge began and it had reached a depth of 35 m by 11.2 ka. The maximum possible age of loess deposits on the two lake plains is about the same.

4.8 Final Summary

The waterlevel of Glacial Lake MacLeod, i.e. 960 m asl (Horberg 1952), dropped to the waterlevel of Glacial Lake Lethbridge, i.e. 930 m asl (ibidem) when the glacier margin abandoned the Lethbridge position. This event likely lead to emersion of minor parts of the MacLeod lake plain, which has an average elevation of 930 m asl. Evidently, full emersion of the MacLeod plain occurred only after drainage of Glacial Lake Lethbridge. That also marked the moment of origin of the segment of the Oldman River Valley that is represented in this area. At the C&P Crushing site, a fluvial erosion surface on

an erosional remnant bevels the relict plain of Glacial Lake MacLeod, and covers an elevation range from 929.6 to 869 m asl. It formed time-transgressively, from the time of drainage of Glacial Lake Lethbridge until the time when the meander loop around the remnant was cut off. Evidently, the Oldman River had already incised its bed to 895 m, 35 metres below the plain of Glacial Lake MacLeod, by 11.2 ka. This is 26 m above the present-day stream bed. Near the Barron site, a plane with similar relative elevations would be 56 m lower than the lake plain of Glacial Lake Lethbridge and at the Van der Heyden site that difference would have been 61 m. The elevation of the present-day floodplain is only 26 m lower than this, indicating that initial rates of river incision may have been considerably higher. Because the two lake plains must have become subaerially exposed at about the same time, the oldest possible ages of aeolian sediments on both lake plains are essentially the same.

The rates of accumulation of loess, based on the presence of the two tephra beds are shown in Table 4.2. At both the Barron site and the C&P Crushing site, the initial rates of loess accumulation immediately following deglaciation were much higher than subsequently. But the values from the Van der Heyden site indicate a lower initial rate. These values are based on information taken from a drill core. Possibly, the core was actually taken from the side of the depression in

Site	Rate of Loess Accumulation	
	11.2-6.8 ka	since 6.8 ka
Barron	0.41 mm/yr	0.25 mm/yr
Van der Heyden	0.18 mm/yr	0.35 mm/yr
C & P Crushing	0.41 mm/yr	0.29 mm/yr
Barron (based on paleomagnetism)	maximum 0.61 mm/yr	N/A
	minimum 0.26 mm/yr	N/A

Table 4.2. Loess accumulation rates for the Barron, Van der Heyden and C&P Crushing sites. Rates are given for the period between eruption of Glacier Peak and Mazama tephra (11.2 - 6.8 ka) and following eruption of Mazama tephra (since 6.8 ka).

the glaciolacustrine silts and clays, so that the thicknesses are not representative of those at the deepest point. Especially, the thickness and the rate of accumulation of the lower loess could be underestimated. The average post-Mazama loess accumulation rates are less variable. These average accumulation rates do not allow for a depositional or erosional hiatus. The numerous buried soils within the loess are indicative of breaks or slowdowns in the depositional regime, although the immature nature of these soils implies that these intervals were short. The loess accumulation rates can be used to estimate the age of the base of these sediments, and hence the time of drainage of Glacial Lake Lethbridge. At the Van der Heyden site, 490 mm of loess accumulated before 11.2 ka. At an accumulation rate of 0.17 mm/a, this would have taken 2882 +/- 100 years, placing drainage of the lake around 14 000 years BP. At the Barron site, 280 mm of loess accumulated before 11.2 ka. At a rate of 0.60 mm/a, it would have taken 467 +/- 100 years for this loess to accumulate, and therefore, the lake could have drained around 11 700 years BP. The estimate of about 11.7 ka agrees more closely with the deglaciation chronology of Clayton and Moran (1982), who assigned an age of approximately 12 300 BP for the Lethbridge moraine. Also, Vreeken (1989) showed that ice retreat from the Lethbridge moraine, sedimentation in glacial Lake Lethbridge, and loess

accumulation on newly exposed surfaces, following drainage of the lake, all occurred over a relatively short period of time, and that these events happened only shortly before 11.2 ka.

A change in loess dispersal systems, sometime between 11.2 and 6.8 ka, is inferred from grain-size compositional differences between the lower and the overlying loess. Dates calculated using the average rates of accumulation for the Barron site indicate that this change could have occurred about 9 to 9.6 ka. Loess deposited before this time is dominated by silt, whereas more recent loess is much more sandy. At some time, this transition might be verified from a radiocarbon date from the shells found at Lethbridge Airport.

The paleosols from the lower loess are much darker than those from the upper loess. This suggests that they formed under different pedogenic conditions, possibly as a result of a change in climate. It is also possible that the colour change reflects an effect of loess aggradation because this should result in drier conditions just beneath the rising surface. At the Van der Heyden, Barron and Diamond City sites, loess accumulation served to fill surficial depressions on the lake beds, resulting in a smoother surface. The soils that developed in this loess would have experienced wetter

conditions than soils that subsequently developed on the better drained surface formed by the thicker accumulations of progressively younger loess.

CHAPTER FIVE

LOESS DEPOSITS AT THE KIPP SITE

This chapter will describe in detail the main study site, with emphasis on the loess deposits at this site. The location and setting of the site will be discussed. The stratigraphy observed from natural outcrops and reconstructed from drill cores at the site will be discussed. Loess thickness and distribution will be examined along with the origin and source of the loess. The composition of the loess found at this site will then be analyzed, citing the field and laboratory evidence. An approximate time-frame for loess accumulation and loess accumulation rates will be determined. The geomorphic processes that occurred in this area and the landscape history will be reviewed.

5.1 Kipp site

The Kipp site was chosen as the main study site because of the thick loess deposits that are visible along the bluffs of the Oldman River (Figure 5.1). The loess deposits form aeolian caps which originate perpendicular to the bluff edge and extend away from the edge eastward to form a discontinuous loess sheet. The loess thicknesses at this site range from 0.5 to 6.7 metres (Vreeken, 1989). Aeolian processes are



Figure 5.1. The Kipp site, located along the Oldman River, has thick loess deposits, light coloured sediments, up to 6.7 metres thick. The loess deposits form caps (C) on the intervening ridges between the coulees, the V-shaped drainage tributaries which drain to the west into the Oldman River. The darker area along the top of the bluffs denotes the limit of the lake plain of Glacial Lake MacLeod (B). The light coloured sediments below the exposed lake plain are the Lenzie silts (A). A radio tower is located on the far right of the photo. Direction of view is north-northwest.

still ongoing at this site, indicated by the recent loess deposits seen in the surrounding areas, especially in nearby fields. These recent deposits are thinly layered loam deposits that consist of sand, silt and clay that overlies present-day soils.

Exploratory data from outcrops and boreholes, including those reported by Vreeken (1989), indicate that thick loess overlies sediments generally attributed to Glacial Lake MacLeod. The character and stratigraphy of this loess mantle are similar to those seen at the reconnaissance sites, described in Chapter four. The Kipp area also includes parallel or aligned coulees whose formation was related by Beaty (1975a) to wind erosion, the dominant wind direction being west southwest. The site is directly adjacent to and down wind from the Oldman Valley, likely a major source of aeolian sediment.

One main objective of this study was to examine a loess-mantled site and to analyze a local area on the basis of its three-dimensional subsurficial structure. The Kipp site meets these criteria by having thick loess deposits overlying glaciolacustrine sediments in an area where some of the main topographic features are a direct result of wind action. Its location directly along the Oldman River also makes it an ideal site to examine the postglacial landscape evolution in

this area.

5.1a Location and setting The Kipp site (Figure 5.2, Table 4.1) is located 5.5 km northwest of the city of Lethbridge, on the lake bed of Glacial Lake MacLeod, west of the Lethbridge moraine. This site, which is directly along the Oldman River, covers an area of approximately 100 ha and contains a cliff exposure approximately 1000 m long and 70 m high. There are also some smaller exposures (1-2 m deep, 1-3 m long) in tributary coulees. A bend in the Oldman river (Figure 5.3), where undercutting due to migration of this meander is still ongoing, occurs at the base of the cliff. The river is located in a valley maximally 3.3 km wide. This site also includes terrain portions with evidence of present-day wind action, including patches of recently deposited dust spread over existing vegetation, and by the presence of a new dugout basin that began to function as a local blowout area, located approximately 1200 m due west of the cliff. The Animal Diseases Research Institute of Agriculture Canada near Lethbridge is located on this site, and tenant cooperation was excellent.

5.2 Loess stratigraphy and distribution

5.2a General observations Stratigraphic observations at the Kipp site were collected from natural outcrops, from

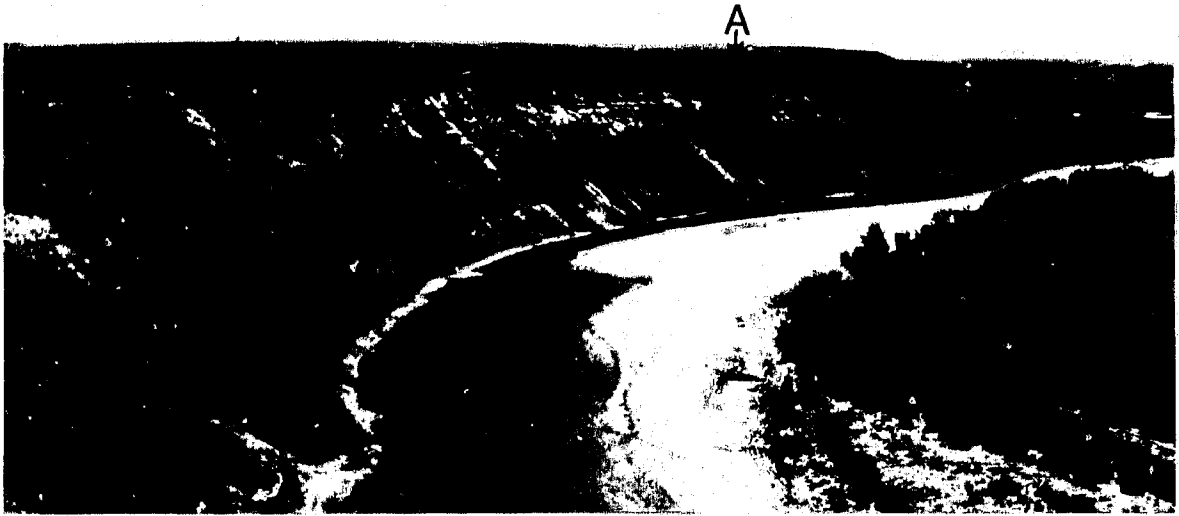


Figure 5.2. The Kipp site located directly along the Oldman River, near Lethbridge, Alberta. The dark sediments (A) along the cliff edge denote the limit of the lake plain of Glacial Lake MacLeod. Direction of view is south-southwest.



Figure 5.3. Air photograph of the Kipp site showing the relative position of the Oldman River. The main topographic features visible in the photograph are the subparallel coulees, which are tributary to the Oldman River. The dashed line outlines the Kipp site.
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boreholes and from a backhoe trench (Figure 5.4). A major exposure along the western limit of the area is formed by the sheer, 70 m high and 800 m long cliff, occurring between stations K1.1 and K3.5 (Figure 5.5). This inaccessible cliff was studied using binoculars.

Several minor outcrops, largely composed of slumped material, were located in the coulees. The only useful one was found at station 2.1 (Figure 5.5). As a consequence of this paucity of good outcrops, most observations had to be collected from boreholes made with a trailer-mounted Giddings soil coring machine. This machine had a 7.6 cm core diameter and was capable of reaching depths of up to 20 metres. The borehole data were collected along five north-south oriented transects that were generally perpendicular to the main topographic relief forms in the area, the coulees. A further reconnaissance of the Kipp site indicated that loess was located on the intervening ridges between the coulees but there was no loess found directly in the bottom of the coulees. Instead, glaciolacustrine rhythmites were observed at the surface in one location in a well-defined thalweg in the side of a valley, angularly cut below the adjacent interfluves.

As a result of this reconnaissance, five transects were set up. One main N-S transect 4 (Figure 5.5, A-B) was

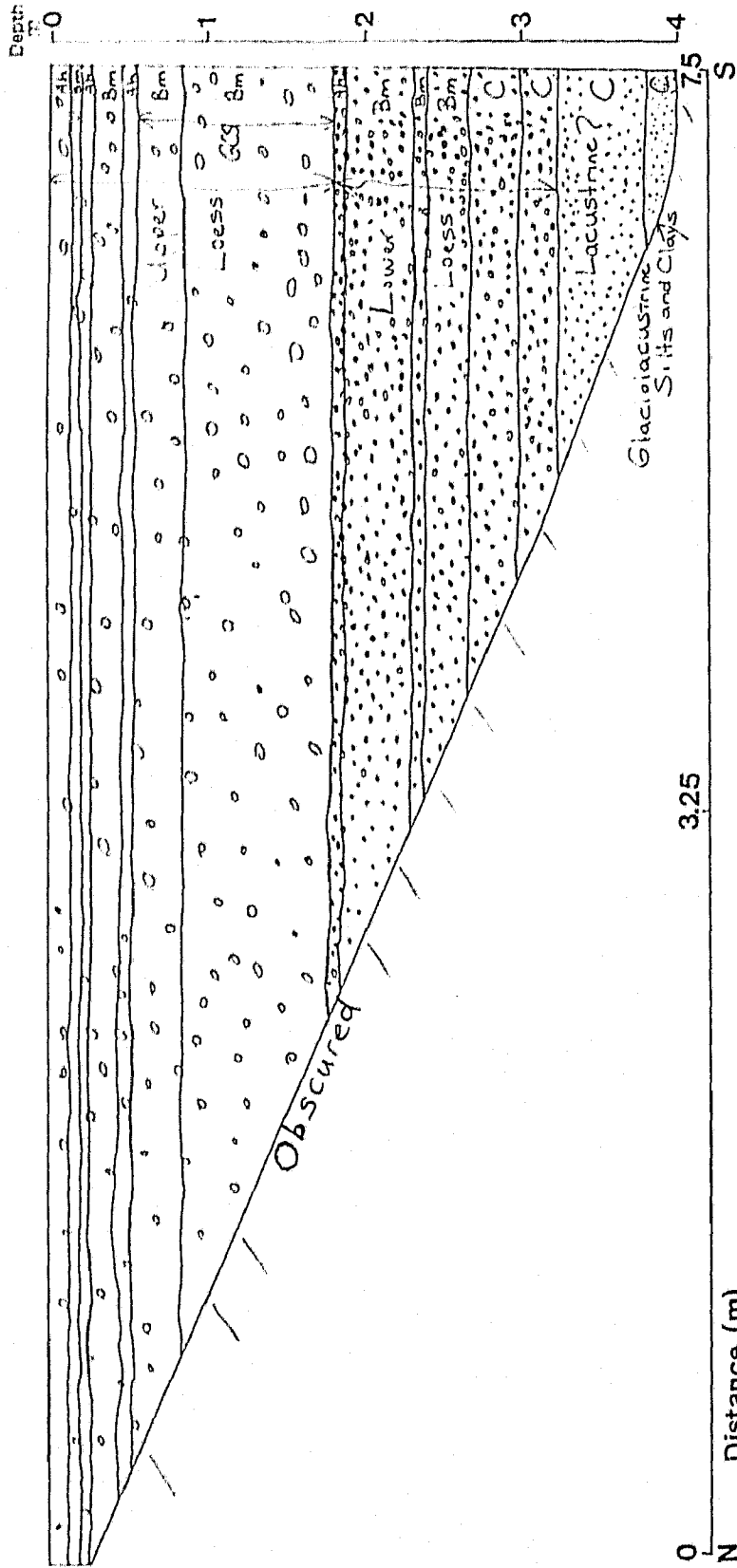


Figure 5.4. Backhoe trench dug along transect four at the Kipp site. The trench showed glaciolacustrine silt and clays at the base, followed by a wet, dark coloured unit, possibly representing a change from lacustrine to aeolian conditions. A loess unit 3.5 metres thick capped the sequence. All the horizons were parallel with the ground surface and no stones, shells or tephra were seen in the entire sequence.

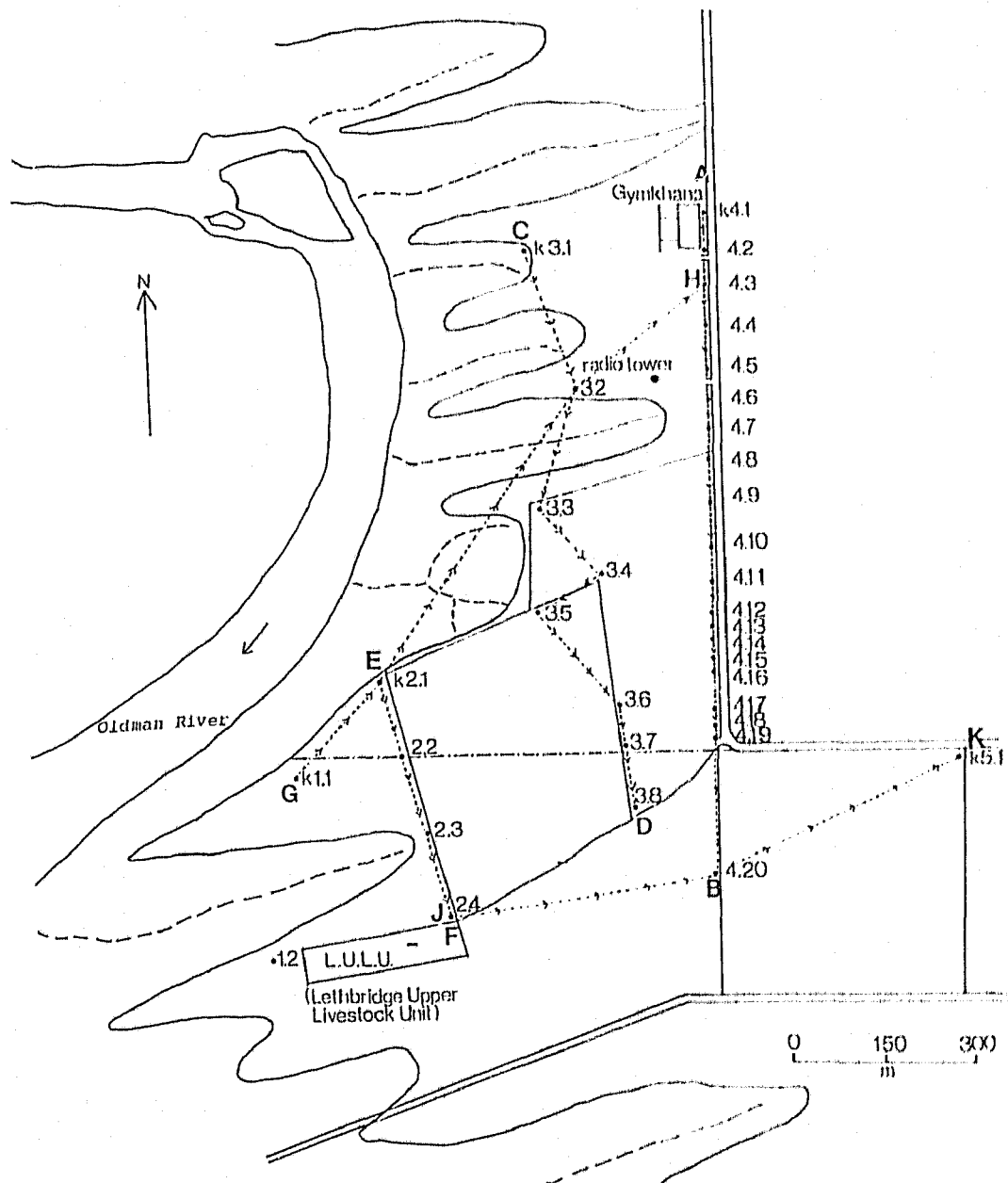


Figure 5.5. Location map of the Kipp site showing the borehole locations, coulees and some of the cultural properties of the area. The transects used in the study are also indicated. Transect 4, A-B; transect 3, C-D; transect 2, E-F; west-east transects, G-H and J-K. Transect 1 consists only of K1.1 and K1.2, and transect 5 of K5.1.

constructed and cored at regular intervals. From this information, the underlying stratigraphy was reconstructed (Figure 5.6). Four shorter transects (Figure 5.5) were also established to give a three dimensional overview of the loess thicknesses in the area. Two of the transects paralleled the main transect. Transect 2 (Figure 5.5, E-F) was located close to the cliffs of the Oldman River, and transect 3 (Figure 5.5, C-D) was located approximately midway between transects 2 and 4. The remaining two transects were located approximately perpendicular to these three transects in a west-east orientation (Figure 5.5, G-H and J-K). The backhoe trench was dug at station K4.13 in order to obtain a better overall impression of the sediment variability. All stratigraphic observations are listed in Appendix A.

5.2ai Stratigraphy The general stratigraphy contained a common basal unit composed of silt and clay rhythmites that accumulated in Glacial Lake MacLeod. The overlying loess deposits were divided into two major units, a lower loess composed of silt loam textured materials, and an upper loess, composed of sandy loam materials. Additional stratigraphic features observed included tephra beds and buried soils within the lower and upper loess, along with sand layers within the upper loess. These buried soils are addressed in this chapter as stratigraphic marker zones. Their pedological attributes are addressed in more detail in

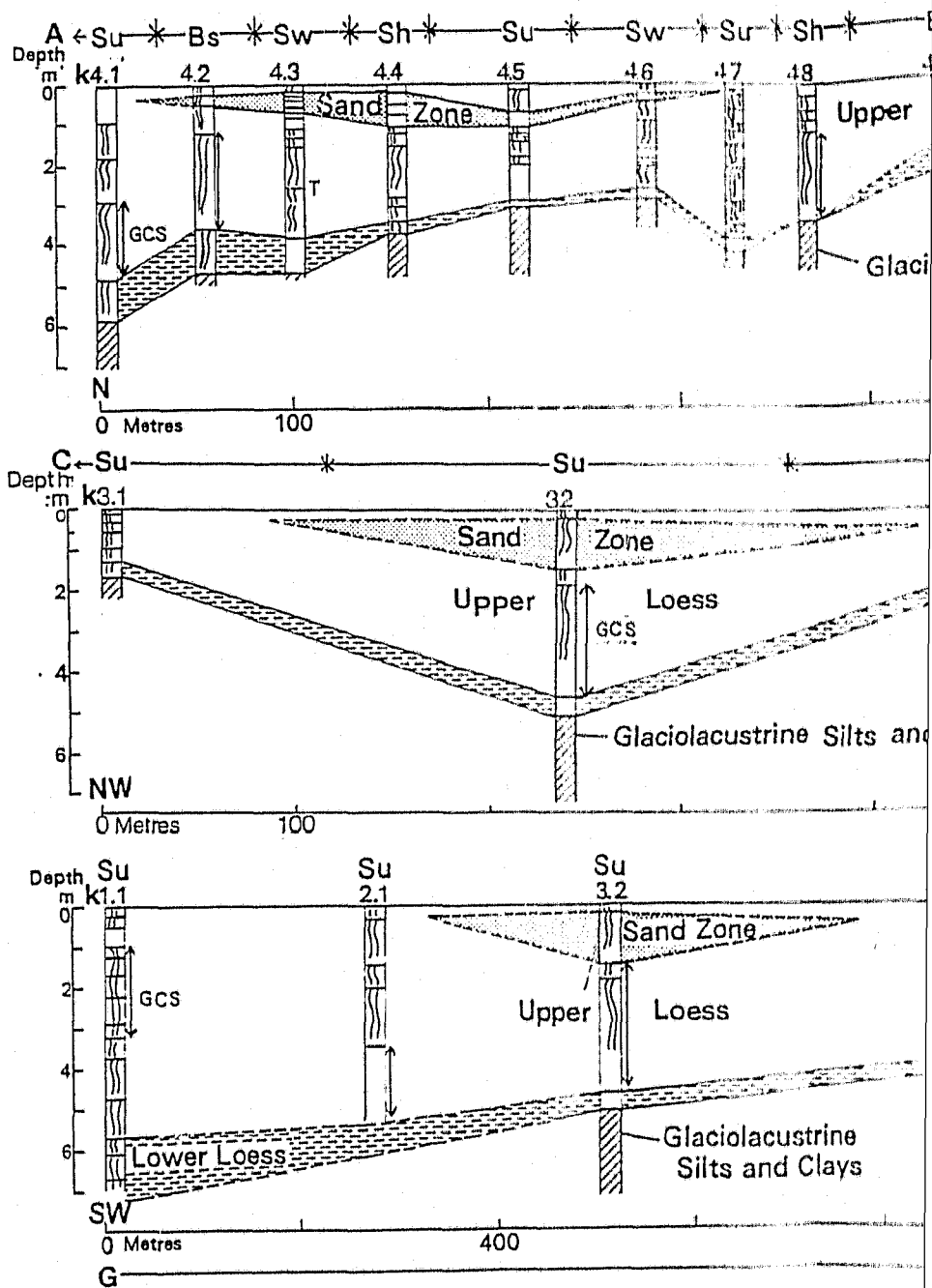


Figure 5.6. Kipp stratigraphy showing transects 4 (A-B) and the two west-east transects (G-H and Figure 5.5). Numbers along the top of the cores borehole site (see Appendix A). Horizontal lines delineate soil horizons. Wavy vertical lines indicate soil solum or intervals of soil formation. Letters at the top refer to topographic position: Su, summit; S, backslope; Bs, backslope; Fs, footslope; Ts, toeslope; Sw, thalweg. GCS, giant cumulic solum, also indicated by vertical arrows. T; tephra.

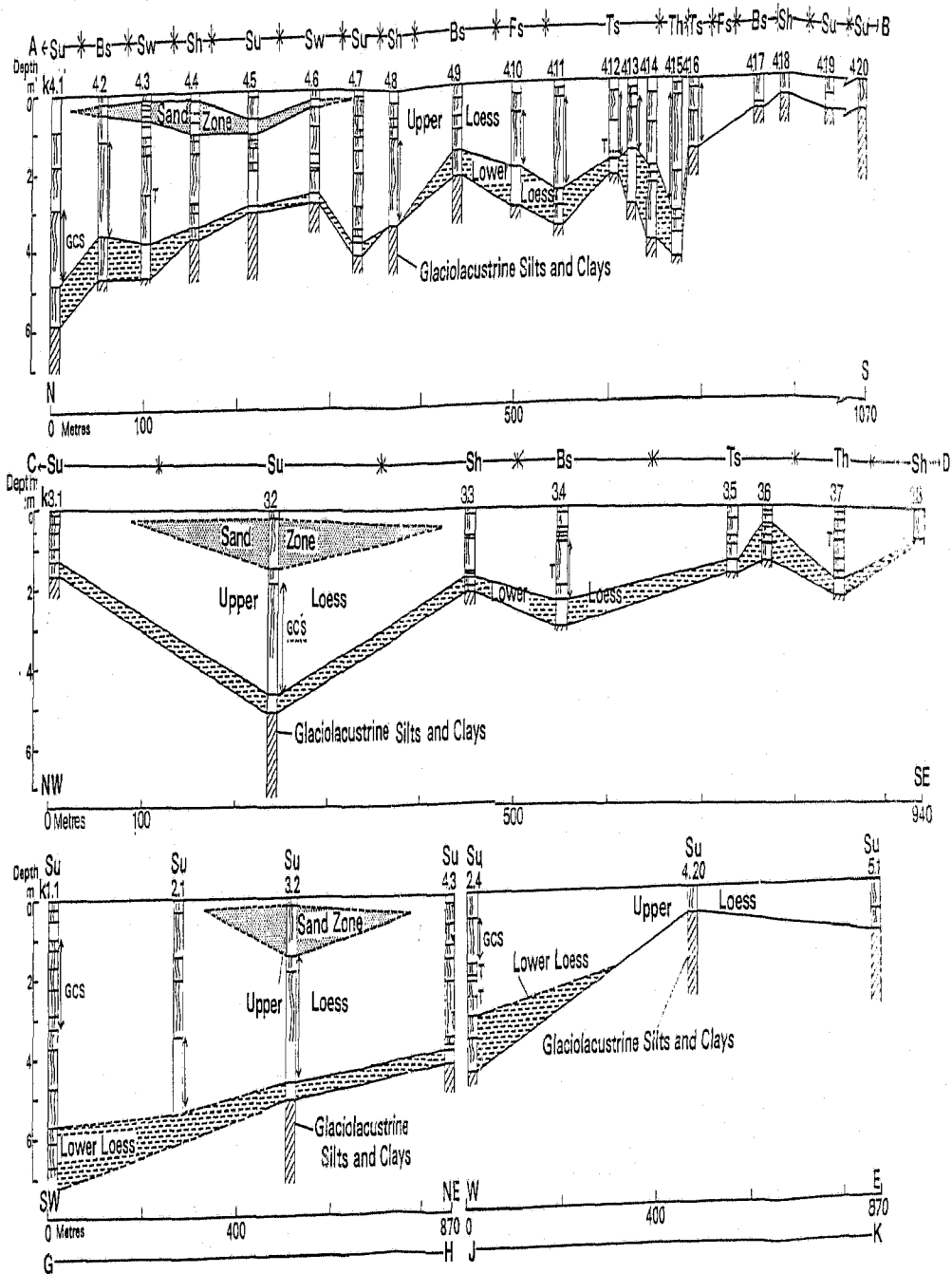


Figure 5.6. Kipp stratigraphy showing transects 3 (C-D) and 4 (A-B) and the two west-east transects (G-H and J-K) (see Figure 5.5). Numbers along the top of the cores refer to the borehole site (see Appendix A). Horizontal lines within the cores delineate soil horizons. Wavy vertical lines indicate soil solum or intervals of soil formation. Letters along the top refer to topographic position: Su, summit; Sh, shoulder; Bs, backslope; Fs, footslope; Ts, toeslope; Sw, swale; Th, thalweg. GCS, giant cumulic solum, also indicated by the vertical arrows. T; tephra.

Figure 5.6. Kipp stratigraphy

Chapter six. The borehole stratigraphy along transects two, three and four was plotted below the ground surface which was treated as a horizontal plain (Figure 5.6). This was done to allow the entire transect to be shown on one page. (Transects two, three and four are drawn with true elevations in Figure 5.8). Because the lower and the upper loess differ, not only in terms of composition, but also in regards to their distribution, they are addressed as separate entities in the following text sections.

5.2b Distribution and Morphology of the Lower Loess

5.2bi Distribution Thicknesses of the lower loess range from 0 to 2.1 m. The thickness map constructed from the borehole data (Figure 5.7) is necessarily sketchy. Because this unit is buried beneath much thicker upper loess, the present land morphology does not offer direct clues to its distribution. But Figure 5.8 shows that the lower loess tends to be thickest beneath low-lying portions of the modern landscape surface such as the footslope and toeslope portions of hillslopes, and also beneath shallow upland swales. More significantly, this unit is thickest in landscape depressions on the glaciolacustrine substrate. The same relationship was observed along the cliff exposure west of stations K2.3 and K1.1, and it is identical to relationships seen at the Van der Heyden, Barron, Diamond City and Popson Park sites (Chapter four). The distribution pattern also appears to reflect the

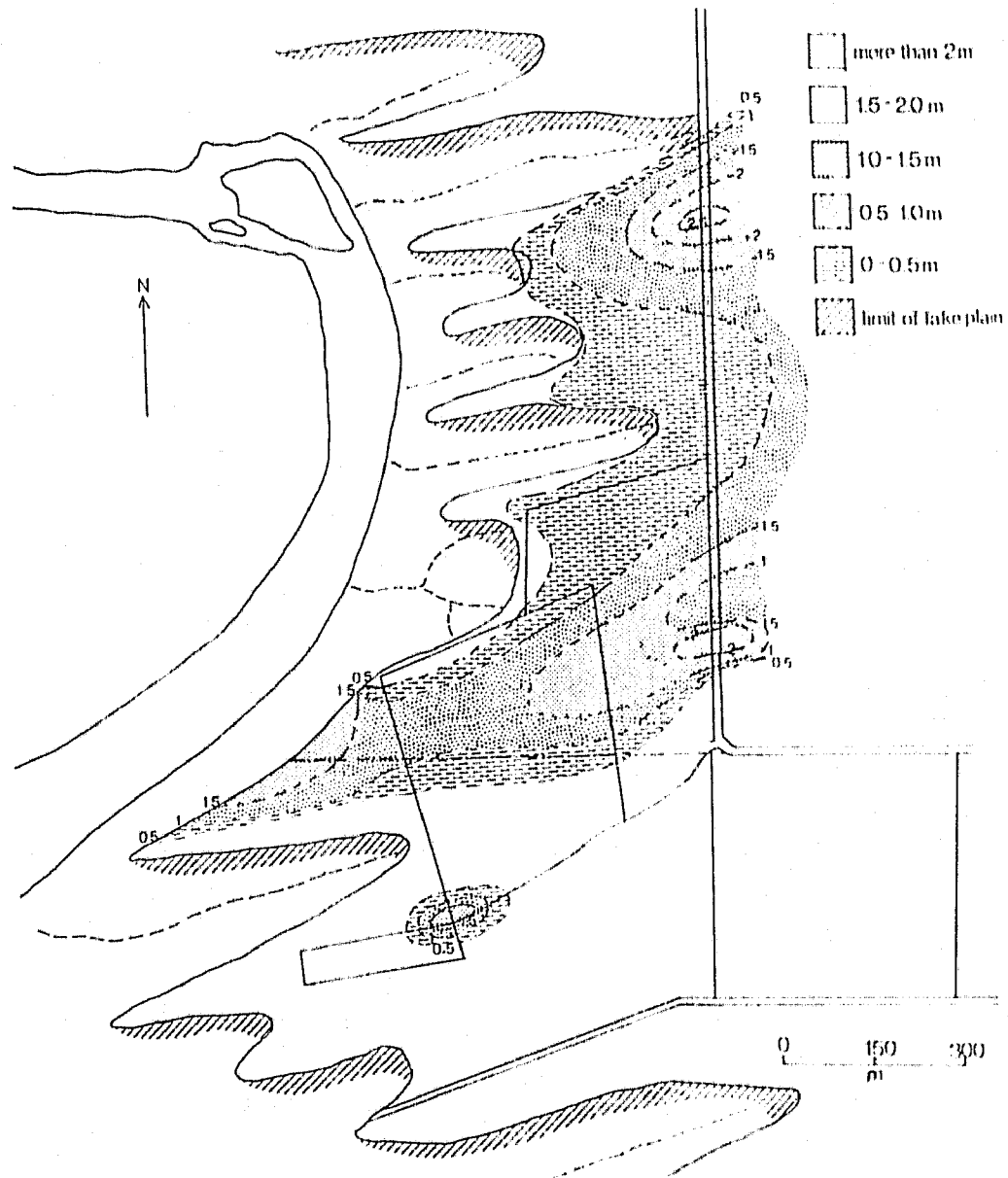


Figure 5.7. Thickness distribution of the lower loess at the Kipp site. Thicknesses in metres.

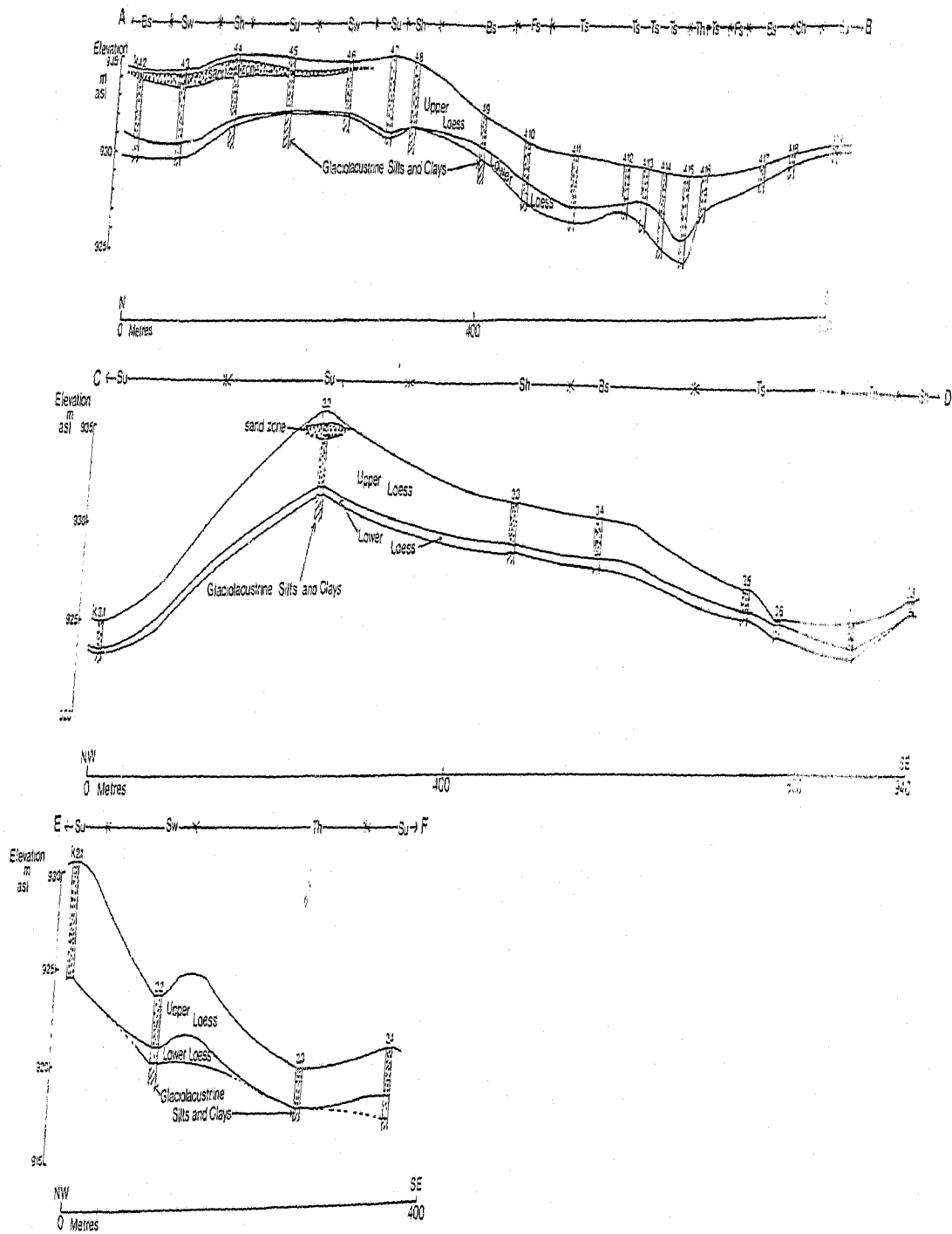


Figure 5.8. Stratigraphy at the Kipp site showing transects 2 (E-F), 3 (C-D), and four (A-B) with actual elevations. Numbers along the top refer to borehole sites (Figure 5.5). Letters along the top refer to topographic position: Su, summit; Sh, shoulder; Bs, backslope; Fs, footslope; Ts, toeslope; Sw, swale; Th, thalweg. Vertical exaggeration 10X.

Figure 5.8. Stratigraphy at the Kipp

effects of localized, postdepositional erosion. This is evident near station K4.15 (Figure 5.8) where the top of the lower loess shows a depression that may extend to station K2.3, i.e. along an E-W trend that follows a coulee that descends the eastern valley side of the Oldman River. This linear depression likely represents a channel, cut by water erosion.

The lower loess is essentially absent from the relatively high terrain to the south of this coulee, with the exception of a local occurrence near station K2.4. In this southern area, the glaciolacustrine substrate contains pedogenic imprints buried beneath upper loess. The absence of lower loess from this terrain portion cannot be attributed to water erosion. If it were, the lower loess should have been removed altogether from the adjacent low-lying terrain. Instead, this absence may reflect either nondeposition, or deflation since deposition, prior to accumulation of the upper loess.

5.2bii Morphology of the lower loess The lower loess contains between 1 and 3 thin, dark paleosols. The greatest number of paleosols tends to occur in stations that were located in topographic low positions. The paleosols in the lower loess tend to be darker in colour than those seen in the upper loess. In the A horizons, the colour ranges from very dark greyish brown (2.5Y 3/2) to light brownish grey (10YR

6/2). The B horizons range in colour from dark brown (10YR 3/3) to light olive brown (2.5Y 5/4). In four of the cores and in the trench, a dark coloured, soft, wet silty loam separates the lacustrine sediments and the loam complex. The lower loess is calcareous at all stations, and almost all the cores show evidence of secondary carbonates in the form of soft, thin, white veins along the cleavage planes. Tephra was found in the lower loess at K3.3. This is tentatively interpreted as Glacier Peak tephra ca. 11.2 ka, because it is in the same stratigraphic position as the confirmed Glacier Peak tephra bed at the Barron site (section 4.2).

5.2c Distribution and Morphology of the Upper Loess

5.2ci Distribution Upper loess thicknesses range from 0.4 to 5.7 m. The thickness map (Figure 5.9) and transect four (Figure 5.8) reveal quite systematic variations with surficial landscape elements. Maximal thicknesses tend to be associated with summits on inter-coulee ridges. They decrease beneath the backslope and increase again beneath swales and thalwegs. But, thicknesses also vary along ridges and thalwegs and higher values along these tend to be located nearest to the Oldman River valley. Apart from these relationships, the upper loess is much thinner to the south of the coulee between stations K4.15 and K2.3. Within this coulee there is a local thickness anomaly at station K4.15 (Figure 5.8) that coincides with a basal depression, earlier

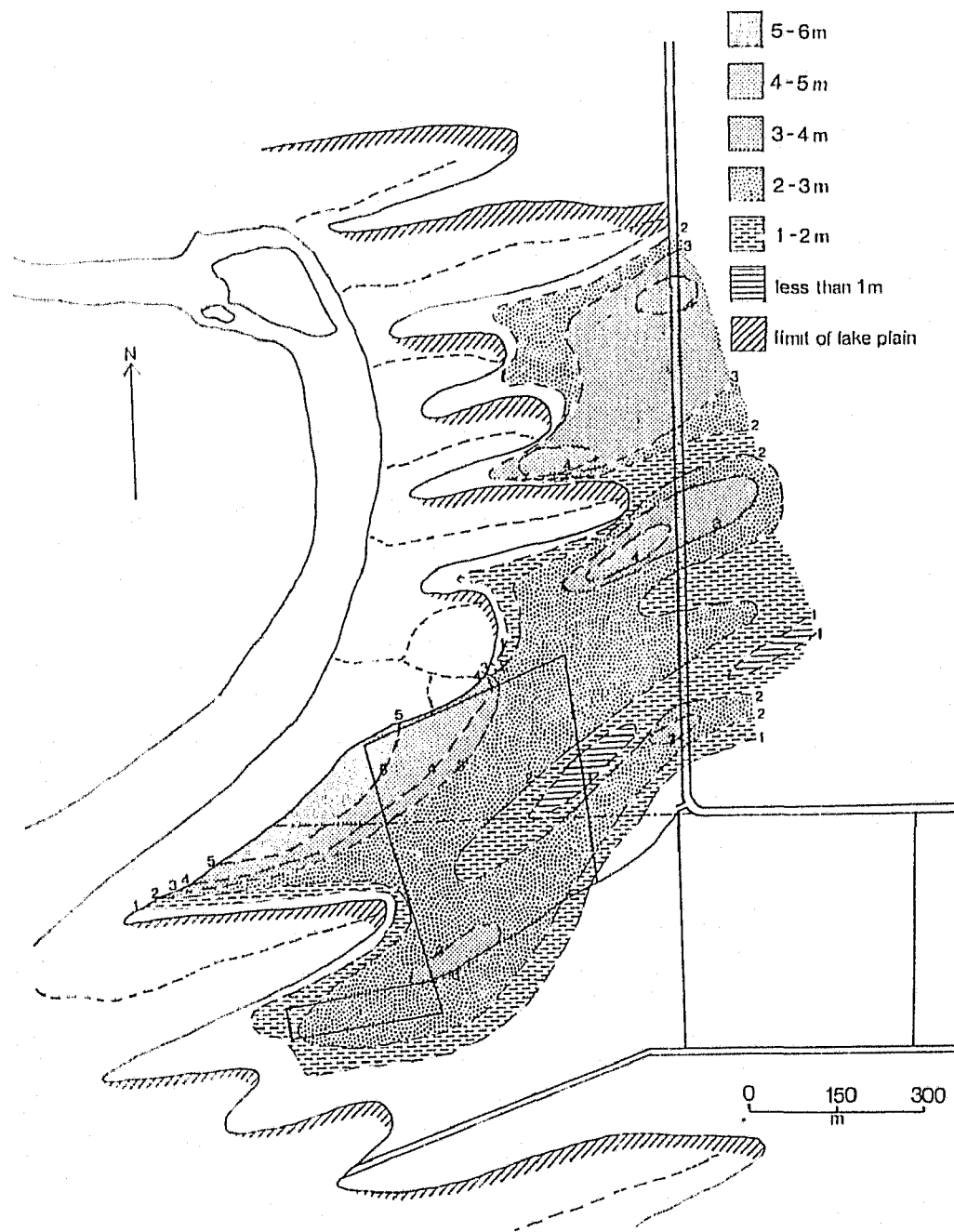


Figure 5.9. Thickness distribution of the upper loess at the Kipp site. Thicknesses in metres.

attributed to water erosion of the top of the lower loess (section 5.2bi). Apart from locations directly adjacent to the dissected and mass wasted valley side, there is no evidence of erosion of the upper loess. The preferred association of maximal thickness with ridge crest portions that are proximal to the valley is apparent from the loess caps that can be inferred from Figure 5.1.

Figure 5.8 shows the elevations of transects 2, 3, and 4. From this figure, it becomes clear that the distribution of the thickest upper loess deposits has been a product of the distribution of the lower loess. The lower loess was deposited in topographic low positions in the glaciolacustrine surface, resulting in a relatively smooth surface on which the upper loess was then deposited. Thus, the distribution patterns of the upper loess is not necessarily indicative of the distribution of the lower loess.

The contrasting associations of thicknesses for lower and upper loess with surficial landscape expression are shown in Figure 5.10. Here, ranges and mean values are plotted in a bar graph, against topographic position (Figure 5.10). The greatest accumulation of the upper loess is beneath the summits or crests of the ridges, and within the coulees. But the greatest thickness of the lower loess occurs beneath backslopes, footslopes, and thalwegs. It must be remembered

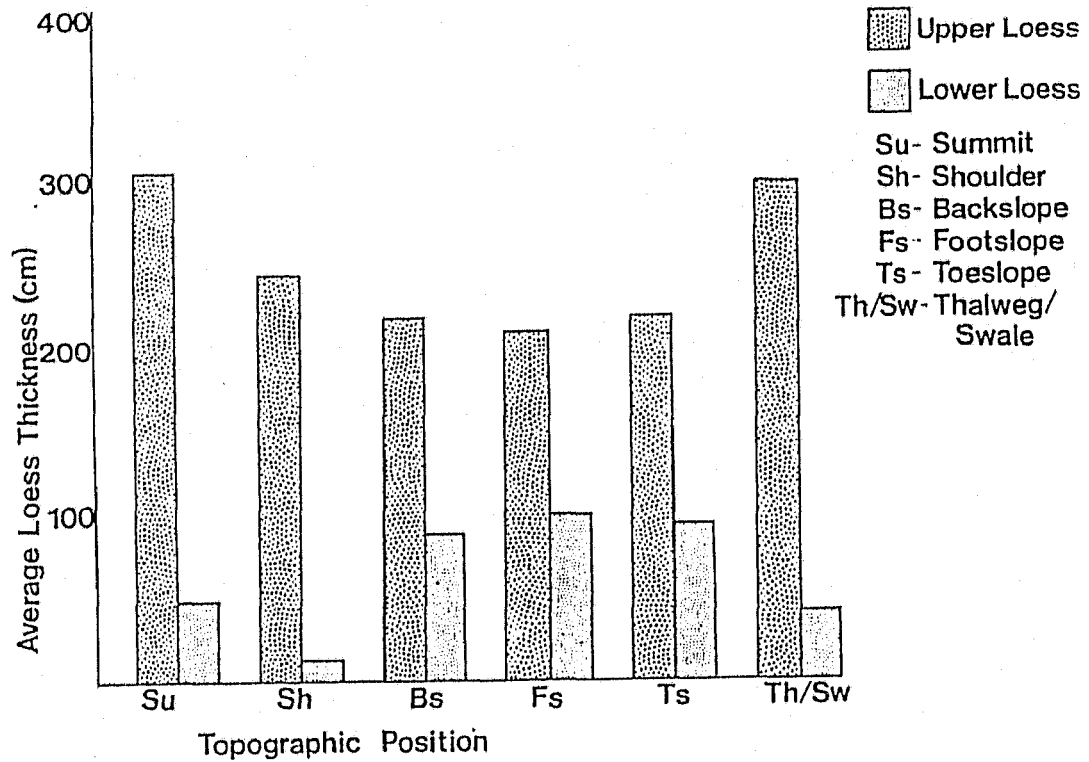


Figure 5.10. Topographic position versus loess thickness for the upper and lower loess. The greatest lower loess accumulations appear to have occurred on the backslopes and toeslopes; however, fluvial erosion of lower loess in swale positions means that the thickest lower loess likely was in topographic low positions. The greatest upper loess accumulations appear to be on the summit and swale positions. Data for K4.6, K4.8, K4.10, K4.12 and K4.15 were used in the computations.

that some stations in swales or thalwegs, such as K4.15, appear to have experienced fluvial erosion of the lower loess, so that the average values probably are not representative of the original lower loess thickness.

These patterns indicate that the lower loess was deposited in topographic lows on the lake plain and that minor fluvial erosion occurred subsequently. Clearly, the contrasting thickness patterns for the lower and upper loess suggest that they are products of different aeolian dispersal systems.

5.2cii Morphology of the upper loess The upper loess contained 1 to 7 paleosols. These paleosols were not usually as dark in colour as those in the lower loess. The colour of the A horizons ranged from very dark greyish brown (2.5Y 3/2) to pale brown (10 YR 6/3), while the colour of the B horizons ranged from dark brown (10YR 3/3) to light olive brown (2.5Y 5/4). With the exception of a few of the surface soils, all of the horizons in the upper loess were calcareous, and many contained secondary carbonates, either as white specks or veins on vertical cleavages. Tephra was found, usually as a pale band in the upper loess of six cores and, on the basis of its position in the stratigraphy of the site, this ash is tentatively correlated with the upper tephra identified at both the Barron and the Van der Heyden sites

(Vreeken 1989) and interpreted as Mazama ash ca. 6.8 ka.

5.3 Grain Size Composition

Figure 5.11 shows the range in textural compositions for the glaciolacustrine sediments and for the lower and upper loess. Bulk analyses for glaciolacustrine rhythmites reveal sand contents ranging from 0 to 5%, silt from 30 to 35%, and clay content ranging from 60 to 70%. These compositions fall within the range for the lower loess. In the lower loess, sand ranges from 0 to 35%, silt from 30 to 50% and clay content from 25 to 70%. The upper loess has sand ranging from 20 to 85%, silt from 25 to 55%, and clay from 5 to 45%. The high sand values in the upper loess correspond to the sand zone at station K4.6. The textural range for the upper loess also includes a distinct subdivision that refers to reworked loess at station K4.15, with significantly higher silt content than the rest, to be addresses shortly. The lower and the upper loess have somewhat overlapping textural ranges but the lower loess contains almost 20% more silt than the bulk of the upper loess when considered at comparable sand contents.

Figure 5.12 shows vertical variations in size composition for the loesses at five stations. The distinction between lower and upper loess is evident. Also, the upper loess is seen to become more sandy in the upward direction, and

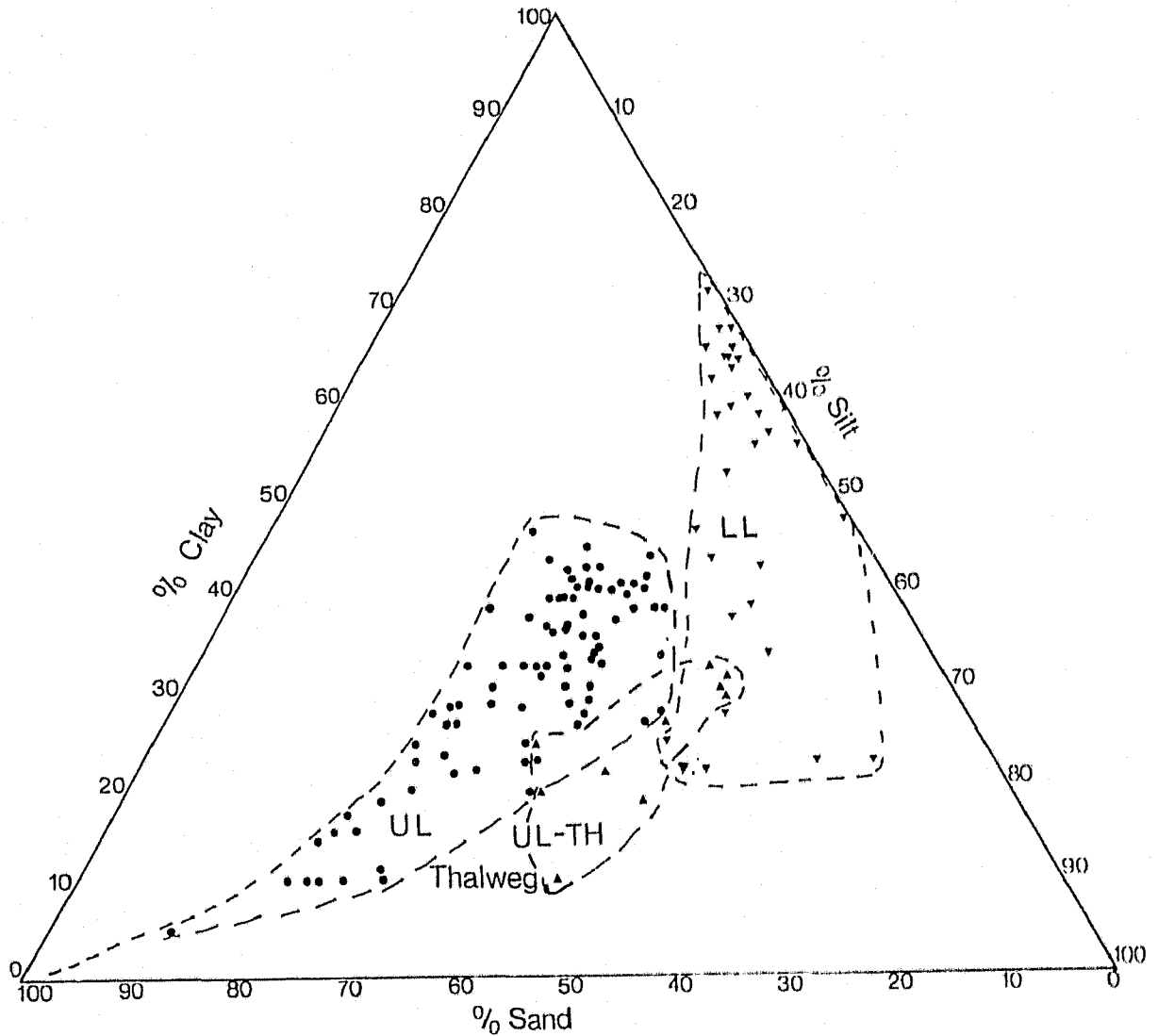


Figure 5.11. Ternary diagram of the particle size distribution for stations K4.6, 4.8, 4.10, 4.12, and 4.15. The upper loess, indicated by the dots is more sandy than the lower loess, indicated by the inverted triangles. The silt-enriched basal portion of the lower loess from station K4.15, indicated by the triangles shows a greater amount of silt and less sand than the upper loess from the remain stations.

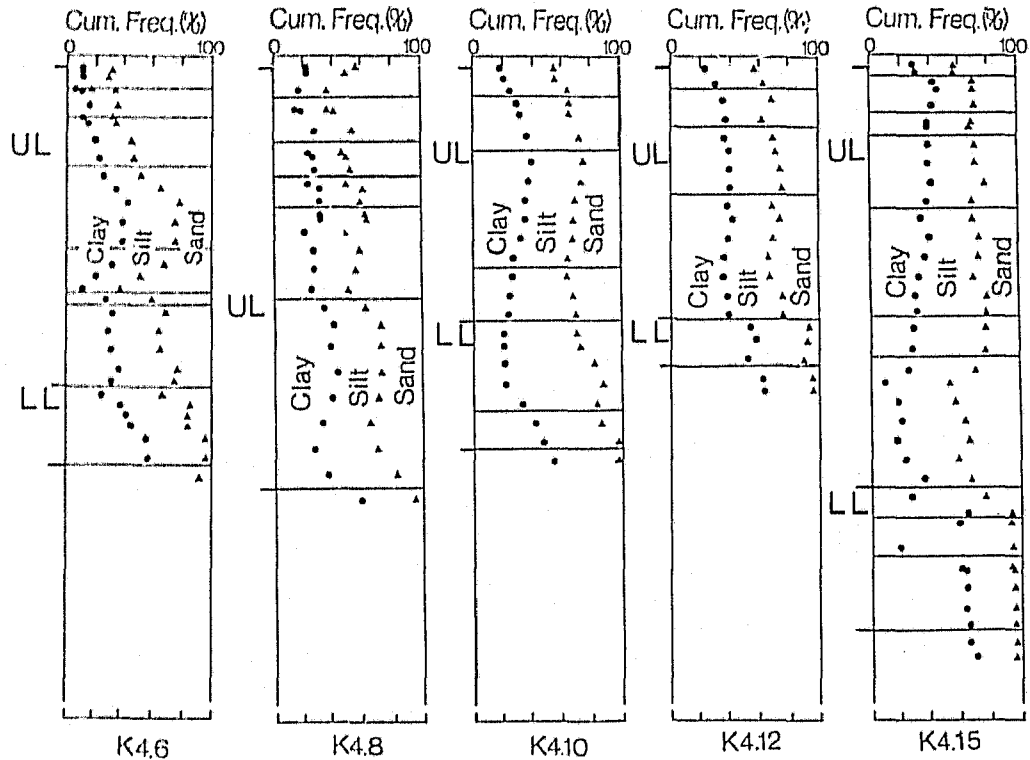


Figure 5.12. Particle size frequency distribution against depth for each of the five cores. The horizontal lines denote soil forming intervals. The upper loess (UL) and lower loess (LL) are also indicated. The general trend evident is decreasing sand content and slightly increasing silt and clay content with increasing depth. In the field, the two main loess units were identified by differences in their texture. Figure 5.12 appears to confirm this hypothesis of an upper sand dominated loess unit and a lower silt dominated loess unit. However, when the particle size frequency distribution is plotted on a ternary diagram (Figure 5.11) this difference in composition becomes even more evident.

progressively so from station K4.15 towards station K4.6. A basal, more sandy subdivision at station K4.15 has no apparent counterpart at the other stations. Clearly, the upper loess displays pronounced three-dimensional textural variability. To characterize this adequately requires a larger data base. The sandy subdivision of upper loess at station K4.15 corresponds to the infilling of the erosional feature in the top of the lower loess (Figure 5.8). This fill has a composition that is intermediate between that of the lower loess and that of the bulk of the upper loess (Figure 5.11). These relationships suggest that it is composed of reworked lower loess material that was deposited during incipient accumulation of the upper loess.

5.4 Age relationships and rates of aggradation

Glacial Lake MacLeod existed between 13 000 and 11 200 BP and its lake bed became subaerially exposed when Lake Lethbridge drained (section 4.7). Accumulation of the lower loess began about the same time on both lake plains, possibly around 11.7 ka. From observations at the C&P Crushing site (section 4.7), it is clear that the Oldman River had incised its bed by 35 m below the plain of Glacial Lake MacLeod by 11.2 ka. Around 9 ka, loess dispersal systems had changed on both lake plains, as estimated at the Barron site (section 4.2). From the distribution of the upper loess at the Kipp site, it can be inferred that it was blown in from sources

within the Oldman River valley. The textural change which is approximately dated at 9 ka indicates that the Oldman River had incised its bed to such a point that a sandy sediment source became available. This could have resulted in a new dispersal system, the one for the upper, more sandy loess.

5.4a Rates of accumulation Tentative rates of loess accumulation loess at the Kipp site (Table 5.1) can be calculated based on the presence of Mazama (?) tephra found in six cores, and on the assumption that loess accumulation began ca. 11.7 ka. The rates of deposition of the lower loess cannot be calculated at this site since Glacier Peak tephra was only identified at one station; however, based on this rate and the lower loess accumulation rates calculated for the Barron and Van der Heyden sites, it seems likely that the rate of lower loess accumulation would be approximately 0.4 to 0.60 mm/a. The average depth to the Mazama ash is approximately 1.90 m or 1900 mm. Thus, the rate of deposition for the upper loess at the Kipp site would be approximately 0.28 mm/a. This is similar to rates calculated for the Barron, Van der Heyden and C & P Crushing sites (Table 4.2). The highest accumulation rates (Table 5.1) occur at K4.3 which is located in a swale and at K2.4 which is located on a summit. The lowest accumulation rate occurs at K2.3 which is located in a thalweg. This low accumulation rate may indicate that some erosion of the upper loess has occurred at this location.

Site	Rate of Loess Accumulation		
	11.7-9 ka	9-6.8 ka	since 6.8 ka
K2.3	N/A	N/A	0.17 mm/a
K2.4	0.51 mm/a	0.41 mm/a	0.38 mm/a
K3.4	0.16 mm/a	0.21 mm/a	0.33 mm/a
K3.7	0.11 mm/a	0.19 mm/a	0.21 mm/a
K4.3	0.32 mm/a	0.57 mm/a	0.38 mm/a
K4.12	0.15 mm/a	0.36 mm/a	0.24 mm/a
Average	0.25 mm/a	0.29 mm/a	0.29 mm/a

Table 5.1. Tentative rates of loess accumulation for the Kipp site, based on tephra interpreted as Mazama ca. 6.8 ka. Pre-Mazama accumulation rates are highly speculative; post-Mazama rates await tephra confirmation.

5.4b Source of loess material The source of the lower loess is believed to be a distal source, perhaps the recently exposed lake plain. The source of the upper loess for this site is interpreted to be the Kipp bluffs, specifically the Lenzie silts (Figure 5.13) which are located directly along the Oldman River. When Glacial Lake MacLeod drained, the bluffs became exposed as the Oldman River incised its bed, and thus were available for erosion by aeolian processes. Beaty (1975a) inferred that the predominant wind direction in this area since deglaciation is west to southwest. Winds flowing across the floodplain to the west of the site would have been forced up the face of the bluffs, eroding the Lenzie silts and later depositing them on the Kipp site. The sandy zone contained within the upper loess is attributed to a localized, temporarily available source.

5.5 Aeolian aggradation

The aeolian record at the Kipp site spans the entire Holocene, and aeolian action continues to this day. The pre-9 ka record is poorly understood. The loess is silt dominated, which suggests it represents a distal facies, and its distribution is spotty, essentially confined to landscape depressions. This absence of directional trends forms a poor basis for inferences as to its source(s) and paleowind directions.

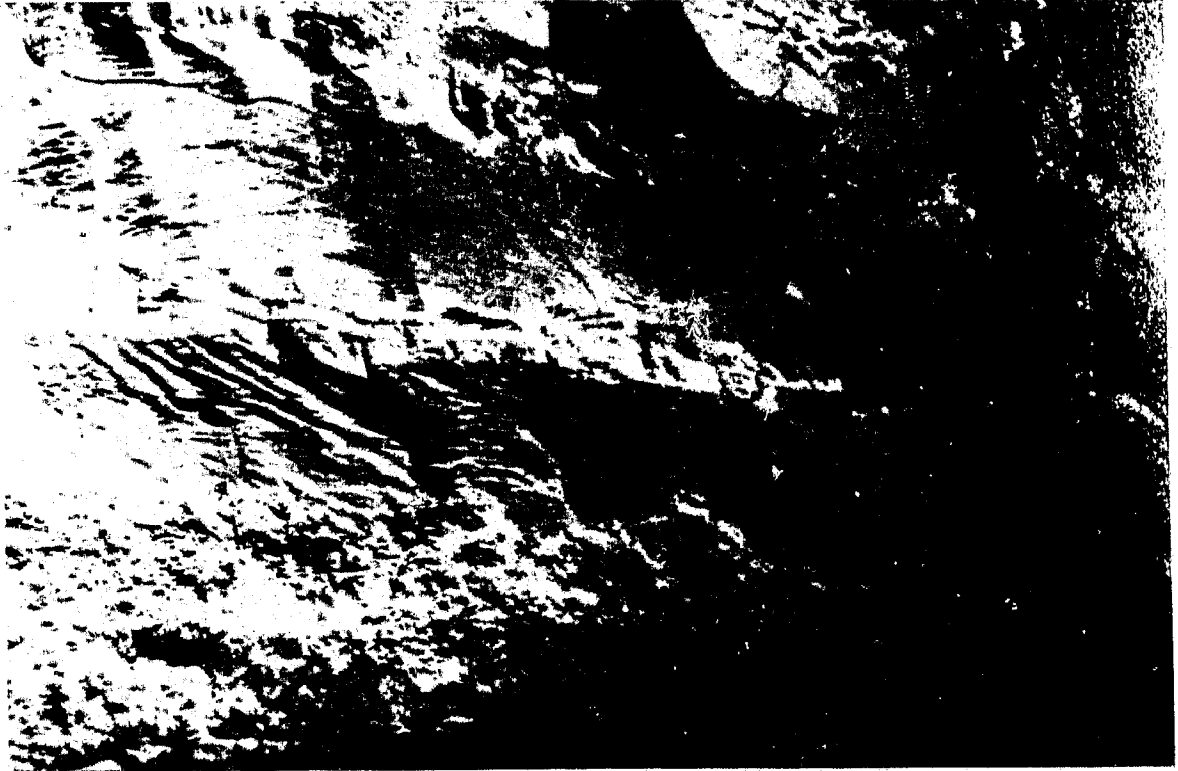


Figure 5.13. The Lenzie silts located along the bluffs of the Oldman River. These sediments are believed to be the source of the upper loess at the Kipp site.

By contrast, the upper loess near Kipp has attributes that are clearly attributable to a valley-based dispersal system. As stated in section 5.4, this same system ca. 9 ka, may represent a response to changes in the valley condition, i.e. an interval of renewed incision of the Oldman River, possibly in response to a change in downstream controls on the river regime. This downward incision was accompanied and certainly followed by lateral migration of the stream bed. These vertical and lateral changes in the inferred loess source area must have resulted in texture of the associated loess deposits at the Kipp site.

Loess accumulations at the Kipp site are in the form of aeolian caps (Figure 5.1) on ridges between coulees with the thickest loess deposits next to the Oldman River valley. Beaty (1975a) postulated that the parallel coulees at this site were a result of strong west-southwesterly wind action, typical for this area. If this were the case, it should have happened before accumulation of the upper loess, and certainly before 6.8 ka, because Mazama tephra beds are found within loess that is exposed on the side of one of these coulees.

5.5a Dispersal system for the upper loess The upper loess represents a well-defined depositional system. The following is an attempt at characterizing this system. At ca. 9 ka, Kipp bluffs stood higher above the valley bottom than 40

m, which was the height already attained by 11.2 ka. Also the bluff was dissected by parallel coulees, roughly transverse to the bluffs, so that the top of the bluffs was ornamented by ridges that added detail to a fixed obstruction to the dominant west to southwest winds in the area.

5.5ai Fixed obstructions Bagnold (1941)

discussed accumulation of wind-blown material in relation to fixed obstructions such as rocks or cliffs in the path of the wind. These obstructions block passage of the wind in such a manner that the result is a shadow or drift directly behind the obstruction. Persistence of this shadow or drift would be dependent upon the continued existence of the object (Figure 5.14a). With reference to the Kipp site, the fixed obstructions above the cliff edge, i.e. the intercoulee ridges could have induced more variety by funnelling the wind along the coulees. This could have relatively enhanced accumulation on the ridges. But some material also would accumulate in the coulees, albeit somewhat farther away from the cliff edge. Downwind, both from the spurs and ridges and from the hanging coulees, progressively less material would have been deposited, because much of the sediment load would already have been dumped. Through these processes, the loess thickness accumulation patterns seen at the Kipp site may have been formed.

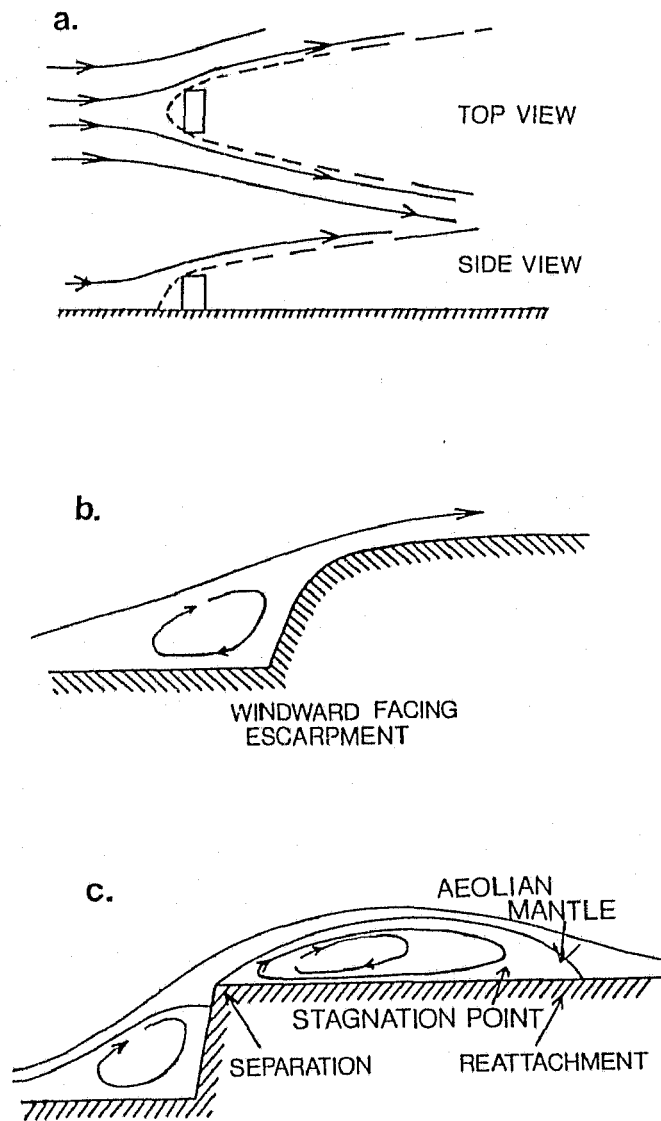


Figure 5.14. Windflow separation. Figure (a) shows the effect of an obstacle on windflow. Continued existence of the obstacle may result in a wind shadow directly behind that object. Figure (b) shows how two-dimensional flow can result at the base of a cliff. This type of flow can result in a stagnation point just beyond the cliff, which may result in an aeolian mantle. Figure (c) shows the flow pattern where separated flow becomes reattached beyond the cliff edge. This type of flow may result in aeolian caps, such as those seen at the Kipp site. (after Bagnold 1941 and Greeley and Iversen 1985).

5.5a11 Flow separations Greeley and Iversen

(1985) discuss windflow separation induced by hills (Figure 5.14b). A cliff, such as the one at the Kipp site, can result in two-dimensional flow in which rotational flow is generated and where the flow near the base of the cliff is in the upwind direction. If separation occurs, the flow will reattach on the upland of the cliff (Figure 5.14c). This type of flow results in a stagnation point just beyond the cliff edge where sediment carried by the flow would be deposited (Greeley and Iversen, 1985). If wind flowed according to this model at the Kipp site, the resultant form could be an aeolian mantle.

5.6 Final Summary

The Kipp site has thick loess composed of two units. Accumulation of the lower loess, directly on glaciolacustrine deposits without any intervening paleosol, must have begun immediately following subaerial exposure of the lake plain of Glacial Lake MacLeod. This lower silt-dominated loess was deposited in depressions on the lake plain. It is not clear whether the absence of lower loess in some parts of the Kipp area is the result of nondeposition or simply due to deflation. Minor fluvial erosion occurred in a coulee thalweg at station K4.15, during the interlude between accumulation of the two loesses. Deposition of the lower loess in depressions or swales on the lake plain resulted in a smoother surface on which the upper loess was deposited. The greatest thicknesses

of lower loess are today found in depressions on the lake plain. The upper loess forms aeolian caps along the bluffs of the Oldman River. The bluffs along the Oldman River are the likely source of the upper loess since it is distinctly sandy and therefore represents a proximal deposition facies. Around 9 ka, with continued incision of the Oldman River a shift in the dispersal system occurred from a silt dominated loess to a more sandy loess. Maximum upper loess thicknesses are found on terrain ridges between coulees. Rates of accumulation for the upper loess since the Mazama eruption at 6.8 ka range from 0.17 mm/a to 0.38 mm/a and were 0.30 mm/a on average. These values are similar to those rates calculated for the Barron, Van der Heyden and C & P Crushing sites. Absence of Glacier Peak tephra (?) at all but one station at Kipp prevent representative calculations of the lower loess accumulation rates; however, lower loess thicknesses correspond to those seen at the Barron and Van der Heyden sites, and thus are interpreted to represent rates of about 0.40 mm/a. The topographic features seen at this site are probably a combination of both erosion and deposition processes. Aeolian processes eroded the bluff escarpment, which was exposed through continuous river incision, and carried sediment through the initial coulees and thalwegs which acted to funnel the wind, until a stagnation point was reached, upon which

deposition of the sediment occurred, resulting in the formation of aeolian loess caps seen in the present landscape.

CHAPTER 6**Soils and Paleosols at the Kipp Site**

The presence of many buried soils within the loess complex of the Lethbridge area indicates that, during postglacial times, soil-forming intervals increased or decreased with more or less intensive aeolian aggradation. This framework is therefore suitable to a reconstruction of the pedological and environmental evolution of the area. In such work, buried soils are used as stratigraphic markers; then they are used to evaluate lateral soil variability within soil-landscapes from specific time intervals and, finally, they are used to evaluate the evolution of soil-landscape variability through time, in this case during the postglacial interval. These three phases in paleopedological analysis require progressively larger data bases. The pedological data base constructed for this study is relatively limited because the paleogeomorphic data base had to be assembled first. Therefore, this chapter discusses soils as stratigraphic markers and deals only with certain aspects of soil succession.

The soils at the Kipp site were studied mainly from borehole observations, because there is a lack of accessible outcrops or exposures. The small diameter of the drill cores

and the large distances between them do not allow for correlation of buried soils between the cores. This limitation necessitates a type of data analysis that is unlike the one applied to frameworks with traceable pedoderms. The soils can only be compared within the broad stratigraphic and sedimentological framework outlined in Chapter five. The present analysis utilizes analytical, morphological (Appendices A and B) and geochronological data.

6.1 Soils as stratigraphic markers

Buried soils within the two loess units at the Kipp site serve to subdivide them into distinct loess increments. The very presence of these soils is indicative of changes in loess accumulation rates.

6.1a Soils in the lower loess The basal part of the lower loess exposed along the Kipp bluff has no buried soils. The upper part and some of the cores contained up to three buried soils. The lower loess accumulated and remained preserved mainly in depressions or swales on the plain of Glacial Lake MacLeod and, to a much lesser extent, if at all, on knolls and associated slopes. The soils are mainly confined to these depressions. There were, however, some summit positions or topographic highs on the lake plain that contained lower loess deposits with numerous paleosols. At

station K4.15 part of the lower loess has been eroded, probably by fluvial action in a channel. Some evidence of soils may have been eroded from the paleoslope before the upper loess began accumulating. Probably, this would have entailed deflation rather than water action, because no evidence of deposition of eroded material was found in the internally drained depressions.

6.2b Soils in the upper loess The upper loess contains as many as twelve paleosols. Every core examined contained at least one paleosol, apart from the present-day soil-forming interval. The greatest numbers of paleosols were encountered in cores from summits or upper hillslope positions.

The large number of paleosols in the upper loess may in part be a result of the change in depositional regime from the lower to the upper loess. The lack of Glacier Peak tephra at this site makes it difficult to determine a truly representative rate of accumulation of the lower loess. However, based on the rates which were calculated, those calculated using an assumed time interval (Table 5.1), and on the rates calculated for the Barron, Van der Heyden and C&P Crushing sites (Table 4.2), it seems likely that the rate of accumulation for the lower loess at this site was the same or slightly higher than that of the upper loess, which may have

allowed for the development of the greater number of paleosols found in the upper loess.

6.1c Soil characterization and postburial changes

During field analysis, buried soils were identified on the basis of their morphology, using descriptive criteria (colour, texture, structure, distribution of carbonates, and horizon boundary attributes). Because those criteria are qualitative, quantitative results from laboratory analysis were needed for additional characterization. It is well known that many soil properties are changed upon burial, so that their diagnostic significance is modified. Insights into the interpretative limitations of those changes will remain site specific until a regional data base permits broader conclusions. This text section addresses soil colour, organic carbon content, carbonate content, and pH with reference to the local framework.

6.1ci Organic Carbon Content and Soil Colour

Figure 6.1 shows the organic carbon content data for the five boreholes that were analyzed. All five cores show a general decrease in organic carbon content with depth below the land surface. Table 6.1 lists ranges of organic carbon for various sediment increments from the five stations, together with corresponding average organic contents that were weighted by the thickness of the actually analyzed sample increments.

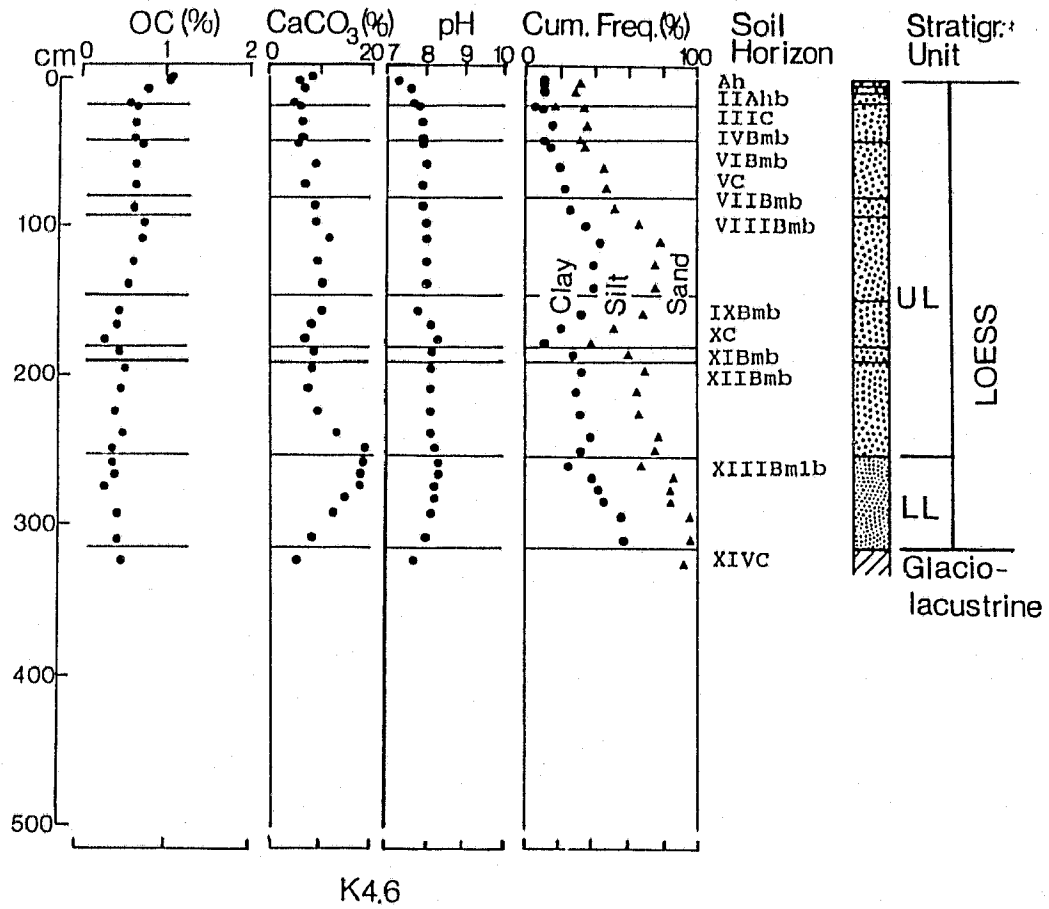


Figure 6.1a. Analytical data collected for station K4.6 at the Kipp site. The percentage organic carbon is depicted against depth to show vertical changes. The same is true of calcium carbonate content, pH and the cumulative particle size frequency. The horizontal lines indicate intervals of soil formation.

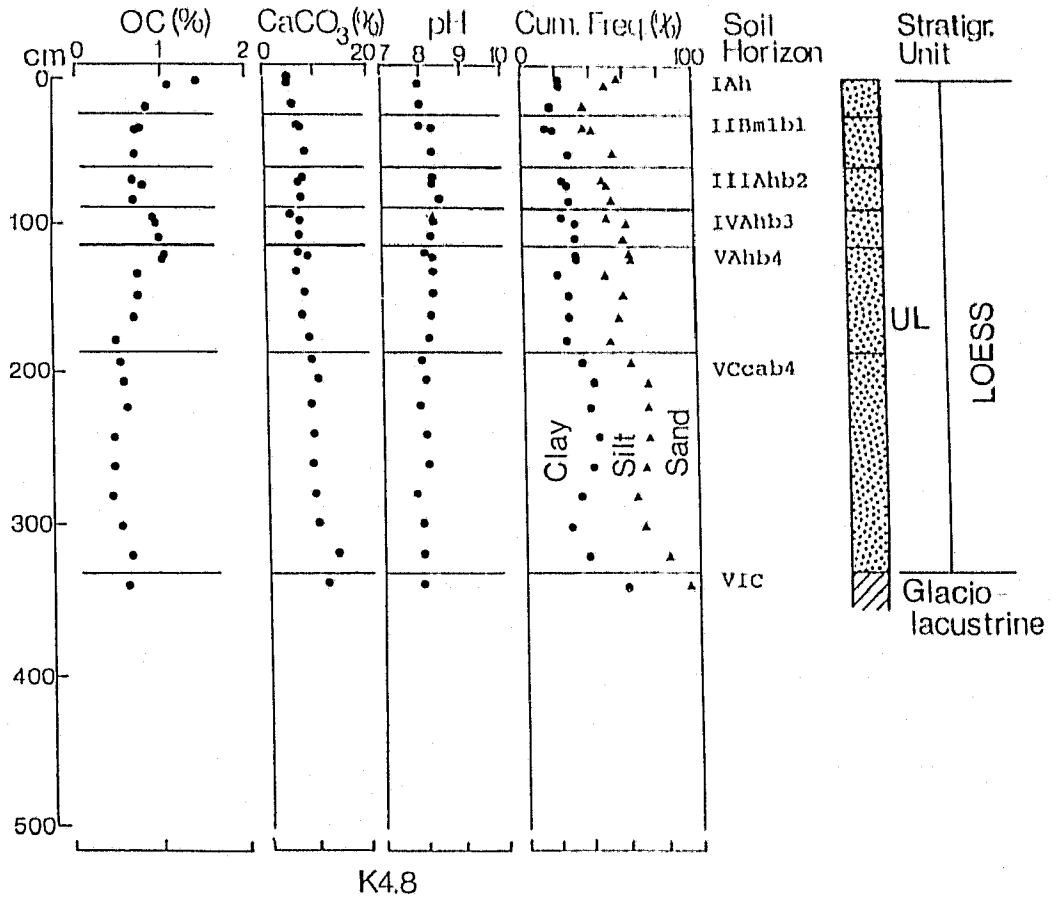


Figure 6.1b. Analytical data collected for station K4.8 at the Kipp site. The percentage organic carbon is depicted against depth to show vertical changes. The same is true of calcium carbonate content, pH and the cumulative particle size frequency. The horizontal lines indicate intervals of soil formation.

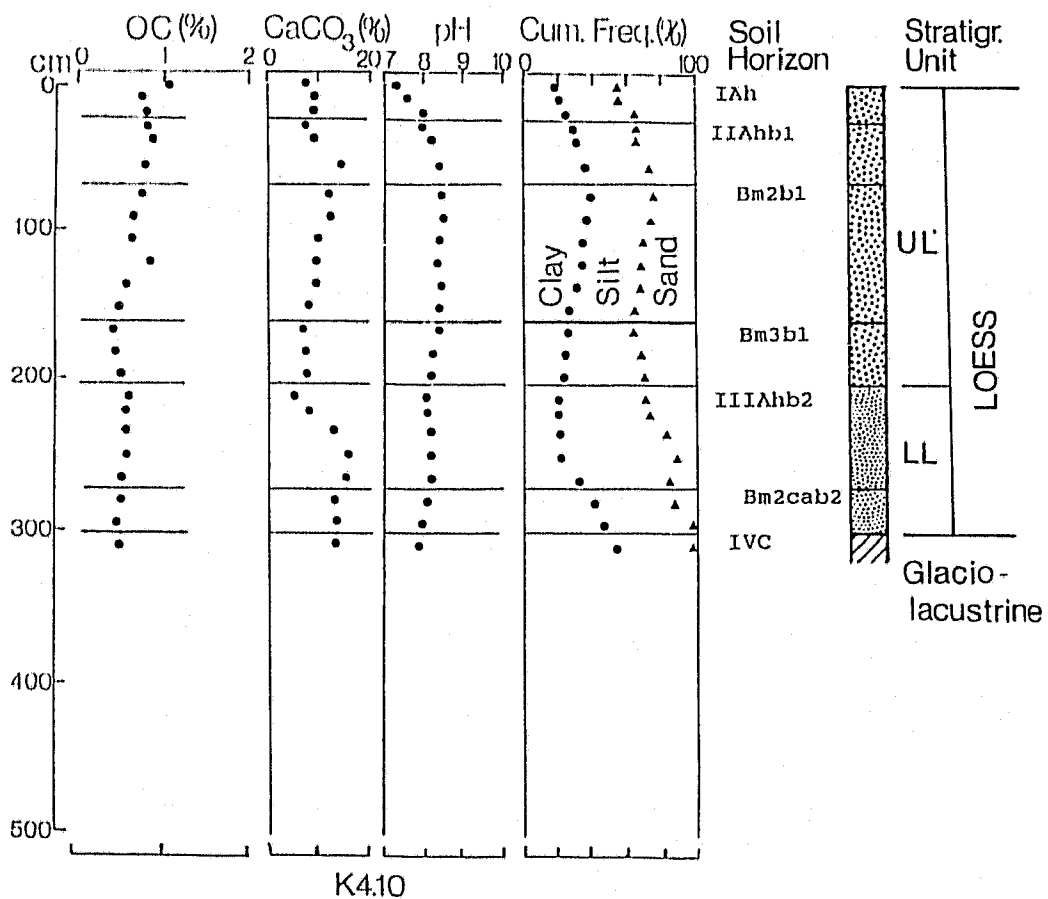


Figure 6.1c. Analytical data collected for station K4.10 at the Kipp site. The percentage organic carbon is depicted against depth to show vertical changes. The same is true of calcium carbonate content, pH and the cumulative particle size frequency. The horizontal lines indicate intervals of soil formation.

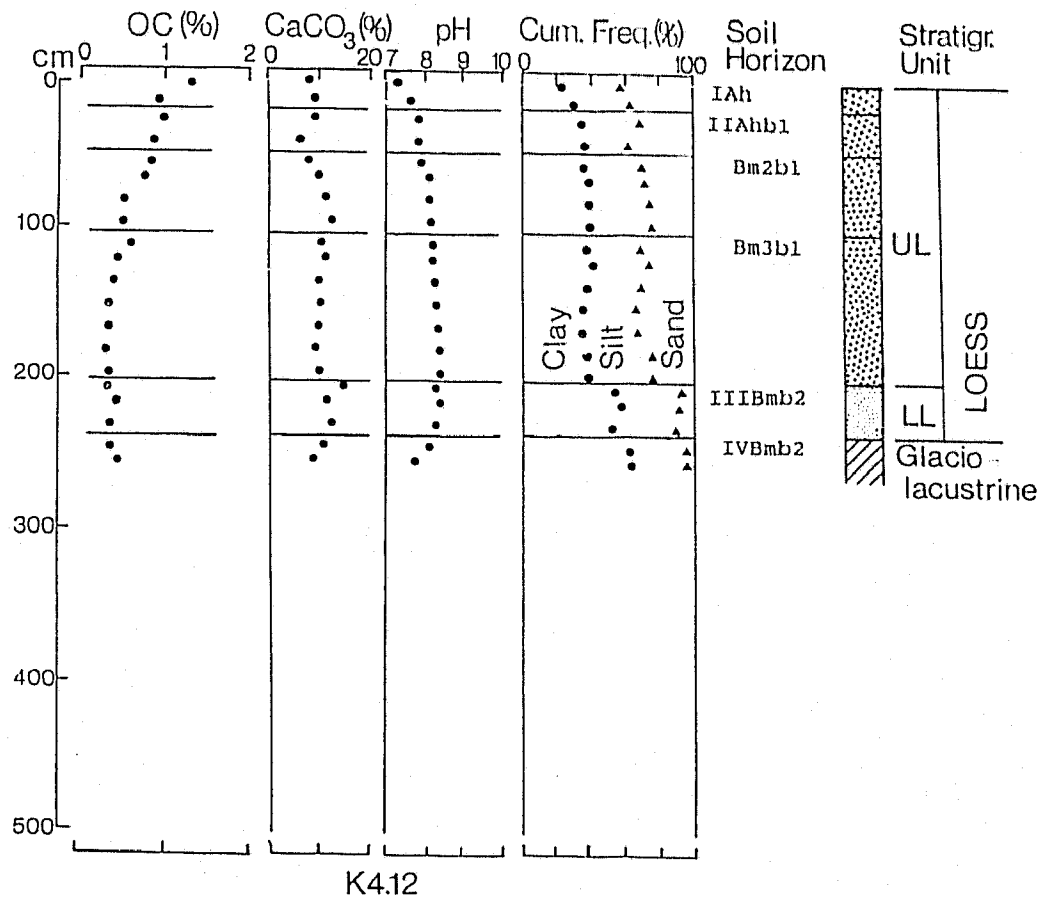


Figure 6.1d. Analytical data collected for station K4.12 at the Kipp site. The percentage organic carbon is depicted against depth to show vertical changes. The same is true of calcium carbonate content, pH and the cumulative particle size frequency. The horizontal lines indicate intervals of soil formation.

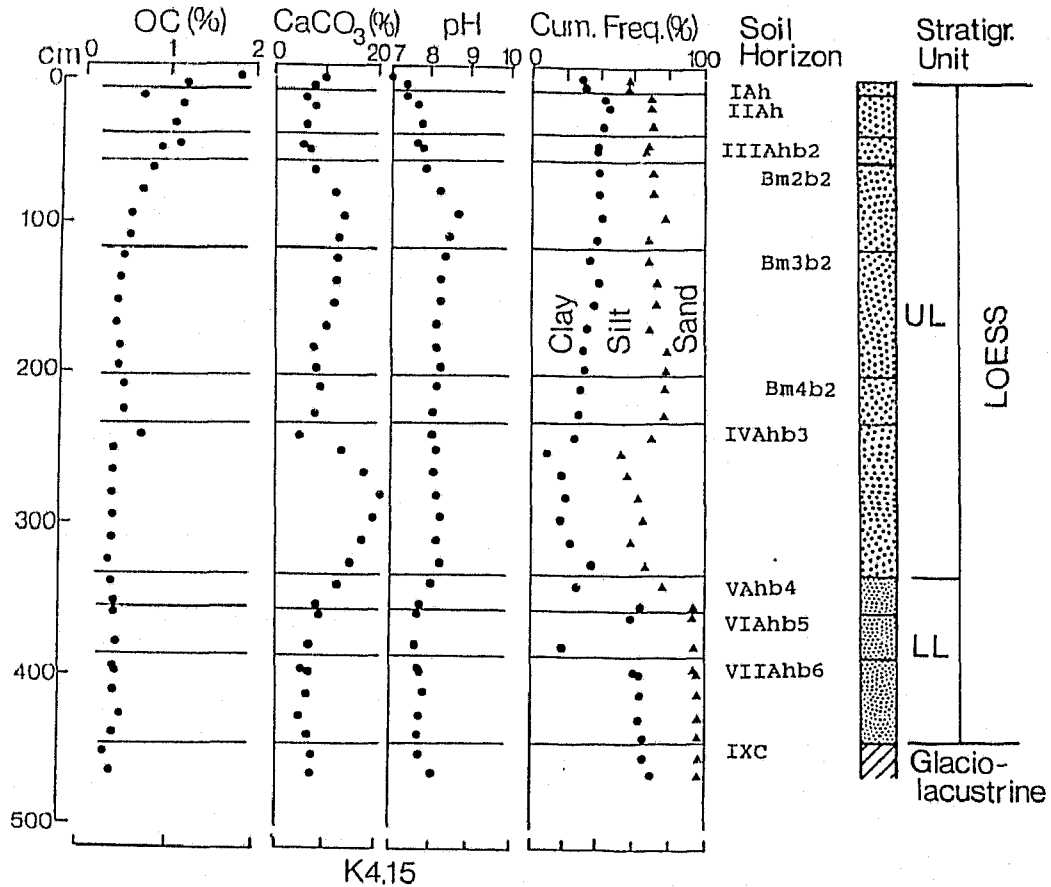


Figure 6.1e. Analytical data collected for station K4.15 at the Kipp site. The percentage organic carbon is depicted against depth to show vertical changes. The same is true of calcium carbonate content, pH and the cumulative particle size frequency. The horizontal lines indicate intervals of soil formation.

Range of Organic Carbon (%)	Site				
	K3.6	K3.8	K3.10	K3.12	K3.15
Upper loess upper 50 cm	1.08-0.58	1.45-0.72	1.08-0.76	1.33-0.90	1.82-0.70
Upper loess below 50 cm	0.76-0.29	1.07-0.46	0.90-0.45	0.87-0.34	0.92-0.32
Lower loess	0.43-0.28	N/A	0.64-0.50	0.46-0.36	0.47-0.36
Total	1.08-0.28	1.45-0.46	1.08-0.45	1.33-0.36	1.82-0.32
Weighted Average	K3.6	K3.8	K3.10	K3.12	K3.15
Upper loess upper 50 cm	0.76	0.93	0.87	1.04	1.15
Upper loess below 50 cm	0.56	0.67	0.64	0.51	0.5
Lower loess	0.37	N/A	0.57	0.41	0.41

Table 6.1. Range and weighted average values of organic carbon content within five stratigraphic columns.

These generalized data illustrate again the overall decrease of organic content with depth but also that most of the lateral variability is confined to the upper part of the upper loess, notably the upper 50 cm increment. Within the latter control zone, average organic content is highest at stations K4.12 and K4.15, which occupy footslope and thalweg positions, and considerably lower at stations K4.6, 4.8, and 4.10 which are on the upper slope positions. This is a commonly encountered soil-landscape association, normally attributed to effects of wetness. Soil organic carbon represents the difference between inputs mostly from plant leaves and roots, and losses, mostly caused by microbial decay (Brady 1990). Plant productivity is generally enhanced by wetness, particularly where it is limited by moisture, while microbial decay can be limited by wetness, albeit mainly by the corresponding lack of soil aeration. In areas with pronounced seasonal drought, such as this one, lack of aeration is at best seasonal, and wetness differences across the local landscape likely have a greater effect on plant productivity than on microbial decay. This may explain the trend of lateral variability. But these overall depth functions are composites of the depth functions for superposed buried pedoderms, each of which may have been overprinted with organics from one or more younger pedoderms. Indeed, in almost all cases where a buried soil was identified in the field on the basis of morphological criteria, the top parts of

those profiles were marked by relatively high organic carbon content, determined in the laboratory. This explains the sawtooth details on the overall depth functions. The fact that the greatest amount of organic carbon occurs in the surficial soil Ah horizons and that successively deeper buried soil A and B horizons, identified in the field primarily on the basis of their relatively dark colour, have lower organic contents raises the following question. To what extent is the dark colour of the buried soils indicative of higher organic matter content? To evaluate this, a comparison was made between soils and buried soils on the basis of organic content and a darkness index. This darkness index was calculated from numerical values for the Munsell colour attributes Hue, Value, and Chroma. This index utilizes a cross product whereby Hue was weighted according to the Hurst Method and Chroma was weighted by a factor of four, while Value numbers were used unmodified (Appendix D). This index was arrived at by a trial and error method and is semiquantitative because the perception of "darkness" is highly subjective. For this index, lower values signify a darker colour. An initial plot of all O.C. (organic carbon) values against corresponding D.I. (darkness index) values revealed a wide scatter of data points. Therefore, the data population was stratified, initially by depth of sample and subsequently by stratigraphic unit, to compare soils from the upper and lower loess complexes, respectively (Appendix C).

Relationships between O.C. and D.I. values for samples from the upper 50 cm of each core analyzed were explored first. Selection of this 50 cm control section was based on the fact that the Lethbridge area corresponds to the Orthic Dark Brown Chernozemic soil zone (Clayton *et al.* 1977) and that these regional soils normally extend to that depth. In other words, this is generally believed to represent the solum, i.e. the depth range of present-day soil process activity and the limit of the common depth range for the roots of the native perennial plants in this region. These data suggest that relatively high carbon contents tend to be associated with soil darkness. This general association encompasses two types of relationships. The first is that within a profile, organic carbon content decreases and colour index increases (indicating lighter colour) with depth (Figure 6.2). This applies not only to the modern profiles but also to the buried profiles. Secondly, whereas the general darkness/organic carbon association is best displayed by the modern Ah horizon and by the buried A horizons, the strength of the covariation, estimated by its slope, is seen to weaken with depth. The buried A horizons have at the same time a lower organic content and a darker colour than the modern A horizons.

The question now arises as to whether or not these

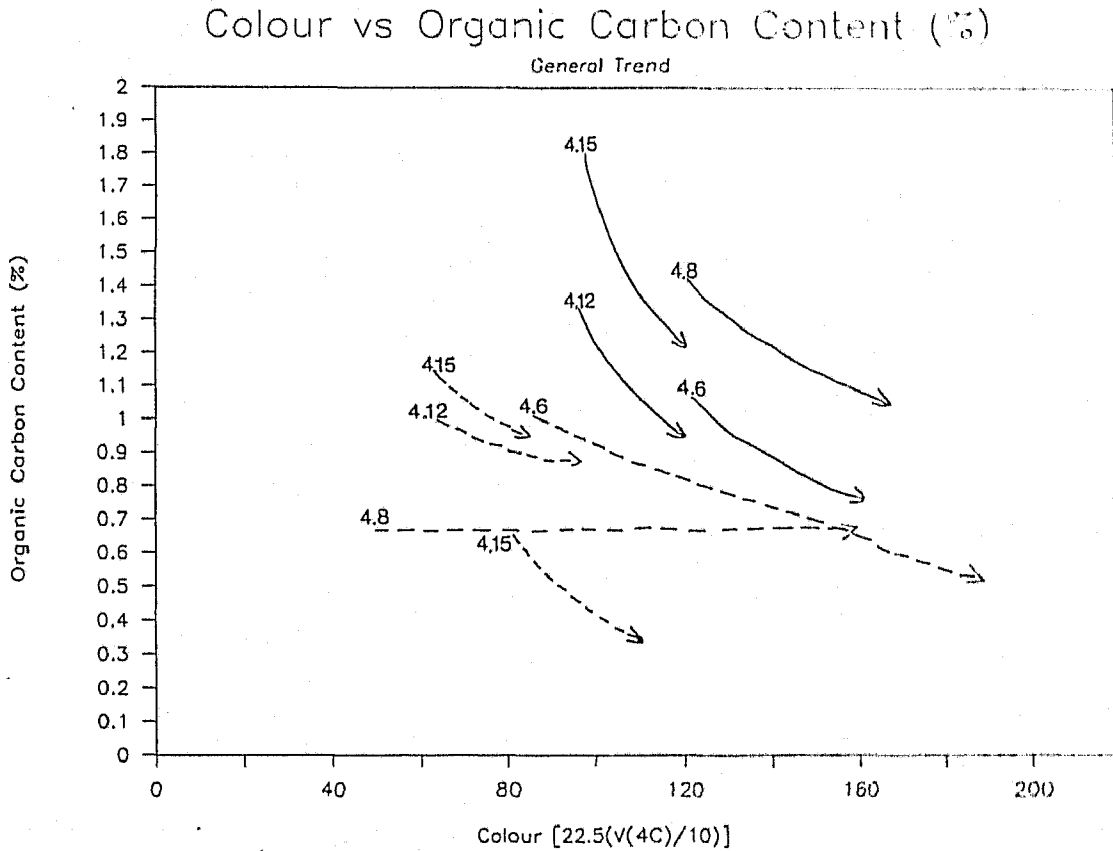


Figure 6.2. Plot of the general trend of organic carbon content versus colour for the upper 50 cm of the lower loess. The A horizons show progressively darker colours with depth, despite decreasing organic carbon contents. The solid lines represent the present-day surface soil, while the dashed lines indicate the first buried A horizon in the upper 50 cm of the profile. Station K4.15 has two buried A horizons within the upper 50cm.

observations can be used to describe relationships in soils located deeper down. These relationships or associations require interim discussion. A strong association between high organic content and darkness as shown by the surficial A horizon samples is a general attribute of soils from the Chernozemic order and, by extension, of Regosols from the grassland regions. This association is implicit in the classification of Chernozemic soils (Agric. Can. Exp. Comm. Soil Survey 1987). It simply means that the soil organic matter has a dark colour. Apparently, part of this O.C.- D.I. association is changed upon burial. This may have to do with the continued postburial microbial decomposition of organic matter (Cooke 1969) that is not replenished by additions of fresh organic residues, as happens in the surficial A horizon. The organic residue left during microbial decay consists of more stable, dark pigmented compounds, probably ligno-proteins. Apparently, horizons that are buried more deeply have lost more of the relatively unstable compounds and have become relatively enriched in dark pigments. It must be considered that these relative losses and gains are reflected by buried A horizons that did not necessarily contain similar organic compounds and similar organic contents at the time when they were buried. Surprisingly, the O.C.- D.I. covariation weakens systematically with progressive depth of the buried soils.

Further comparisons between O.C. and D.I. reveal that there is no significant trend for samples from the lower part of the upper loess (deeper than 50 cm) and for those from the lower loess. The observation that buried A horizons from these sediments are darker than their associated B horizons is not necessarily heuristic, because identification of buried A horizons utilized criteria that were not confined to soil colour.

The darkest soils were found in the lower loess, but they contain the lowest amount of organic carbon in each of the profiles. The lower landscape positions, at K4.10 and K4.15, contained the darkest amongst these dark soils, whereas paler soils were found in the higher landscape positions, at K4.6 and K4.12. The amount of organic carbon that was present in the buried soils in the lower loess was uniformly low, ranging from 0.28 to 0.64 % (Figure 6.1). The buried A horizons did, however, have darker colours than associated underlying B horizons. Because modern A horizons contain more organic carbon than their B horizons, it is likely that the dark A horizons from the lower loess contained much more organic matter before they were buried, although the present-day differences are negligible. Until the relationships between pigmentation and organic matter content in surficial soils are known, all inferences on the former organic content of these ancient soils based on their residual pigmentation is purely

speculative.

6.1b Calcium Carbonate Content and pH Contents of calcium carbonate in five cores are shown in Figure 6.1. These graphs show an overall trend of slightly increasing calcium carbonate content with depth. Many details are superposed on this trend. In places, low values appear to relate to the upper boundaries of paleosols that mark the top parts of successive loess increments. Elsewhere, such boundaries are marked by high values. These complex patterns likely reflect redistribution of both primary and secondary carbonates. The primary carbonates are those that formed part of the loess when it accumulated; secondary carbonates were dissolved and redistributed, possibly several times, since deposition. Morphological evidence of such redistribution was found in each outcrop and in each core. It consists of soft, pure lime nodules, lime coatings along natural planes of weakness, and fine lime mycelium throughout the groundmass.

In modern surface soils on stable land surfaces in the Lethbridge area, decalcification is evident in soil A horizons whereas redistribution and recalcification is evident from the abundance of such secondary carbonates in the B horizon. The same processes likely occurred in the past, when the presently buried soils were at the land surface. Upon burial, those soils would have been enriched with carbonates contributed

from their calcareous overburden. This explains the fact that all buried soils from the five cores are calcareous. Some surface soils at the Kipp site have been partly decalcified, (i.e. at K4.8, 4.10, and 4.12) as is evident from their carbonate depth function, but others have not (i.e. K4.6, and 4.15). It must be remembered that this is an unstable land surface and that calcareous dust continues to accumulate to this day. As a consequence, there is considerable carbonate variability in surface soils, and the same likely applied to the soil-landscapes from the past, at the Kipp site.

The core data contain evidence that at least one major cycle of carbonate translocation occurred in the remote past (Figure 6.1). For example, the paleosols in the top of the lower loess have low carbonate values at K4.10, but much higher values at 4.6, 4.12, and 4.15. This is inconsistent. On the other hand, there are distinct bulges in the carbonate depth functions near the top of the lower loess. At K4.6 and 4.12, this bulge straddles the stratigraphic contact, at 4.10 it is below it, and at 4.15 it is above it, whereas at 4.8 the depth function is relatively featureless. The variable position of these bulges is a good indication that a major carbonate redistribution cycle occurred since burial of the lower loess. The timing of this cycle may be estimated by locating the depth to the top of the first buried soil above this conspicuous carbonate bulge. This depth is at 190, 210,

205, and 240 cm at stations K4.6, 4.10, 4.12, and 4.15 respectively. The average value is 210 cm, close to 200 cm, which, based upon the average accumulation rate of 0.29 mm/a for the upper loess, would correspond to a time plane of about 7 ka. This is probably a maximum age estimate for this carbonate cycle.

Other more recent carbonate cycles can be inferred from the depth functions, i.e. at K4.10, 4.12, and 4.15 (Figure 6.1). These, however, have no common relative depths and they are far less conspicuous. Nevertheless, their presence is evidence of cyclic change in the conditions that governed carbonate distributions.

There is also a definite trend related to the major topographic position in each of the cores. Cores K4.8, K4.10 and K4.12 all show increasing amounts of calcium carbonate from the surface soil until the first buried A horizon, likely due to deposition. K4.6 and K4.15, which are in topographic low positions, did not show such a trend. Instead they showed higher amounts of calcium carbonate at the surface, decreasing with depth. This trend may be indicative of new inputs of calcium carbonate from new aeolian deposits or it may reflect new inputs from downslope eluviation. The basal part of the upper loess deposited in K4.15 contains significantly higher amounts of calcium carbonate than the remainder of the

profile, or in any of the cores. This material also contains significantly more silt than the upper portion of the upper loess at this or any other site. Likely this material is redeposited lower loess with aeolian inputs (see Chapter five). Thus, there is strong evidence of an erosional phase at this station by fluvial action.

The pH values for the five columns are shown in Figure 6.1. These graphs indicate a general trend of increasing pH with increasing depth within the upper 0.50 m at four stations and within the upper 1 m at K4.15. The pH values range from 6.5 to 9.0, but most range from 7.5 to 8.5, which is generally the range for soils of arid regions (Brady, 1984). Calcium carbonate has a pronounced influence on pH because it is a salt of weak acid, and saturated solutions of it have a pH of 8.2. Thus, calcareous materials will always have a pH greater than 6.5, whereas those that are calcareous throughout should have a pH close to 8.2.

Figure 6.3 shows the calcium carbonate content compared with the pH while Table 6.3 shows the ranges. Indeed, several fields can be delineated within the scatter plot. Low carbonate contents, i.e. essentially from 4 to 10%, correspond with pH values ranging from 6.9 to 8.5, whereas carbonate contents above 10% are associated with pH values of 8 or more.

Calcium Carbonate Content versus pH

K4.6, K4.8, K4.10, K4.12, K4.15

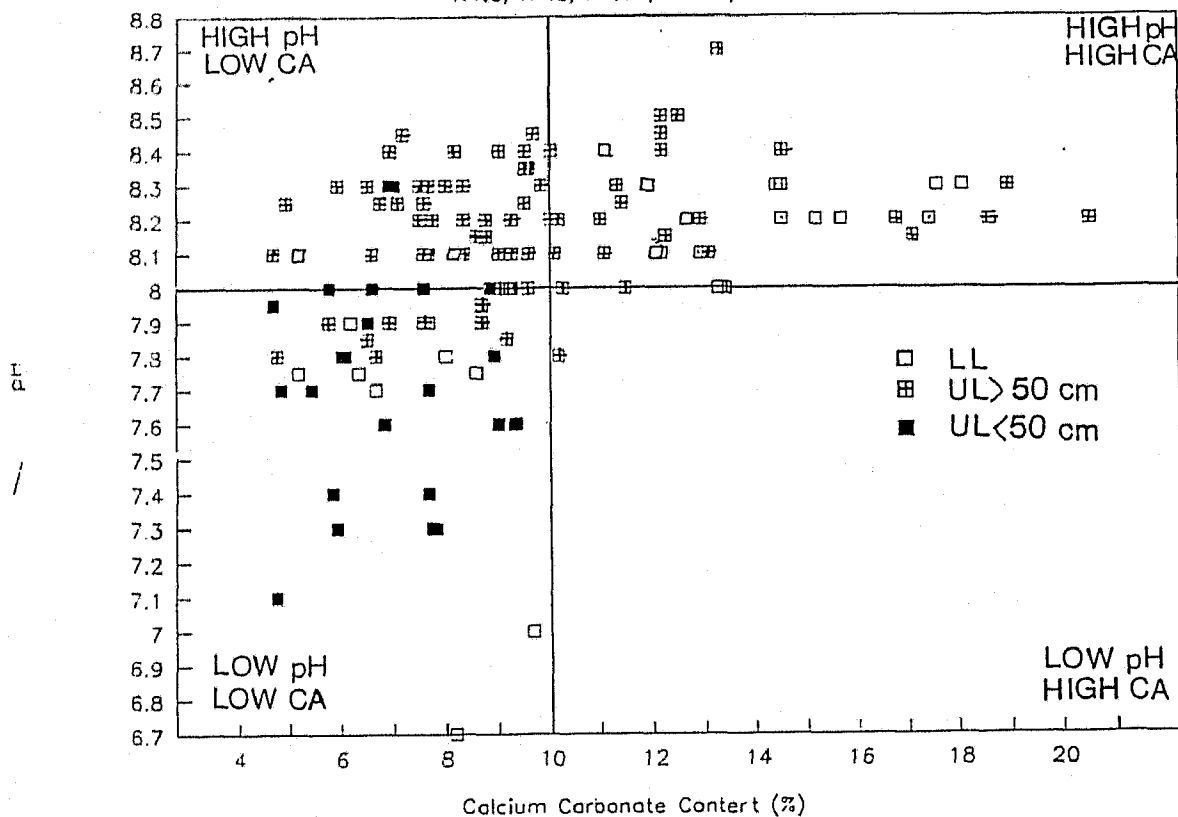


Figure 6.3. Plot of calcium carbonate content versus pH for K4.6, 4.8, 4.10, 4.12, and 4.15. This scatter plot, a pH of 8 serves as a divider of samples with high carbonate contents. The boundary for pH 8 was chosen because this is approximately the pH of saturated solution and therefore this line may approximate in natural samples the pH of solutions saturated with calcium carbonate. The boundary of 10 for the calcium carbonate content was chosen because it is chemically incompatible to have samples with pH lower than 8 and calcium carbonate contents higher than 10%.

Range of Calcium Carbonate Content (%)	Site				
	K4.6	K4.8	K4.10	K4.12	K4.15
Upper loess upper 50 cm	4.83-8.17	4.67-6.58	7.58-9.33	6.08-9.0	5.42-9.67
Upper loess below 50 cm	5.75-18.5	4.92-13.25	6.92-14.5	7.67-12.2	4.67-18.9
Lower loess	12.1-18.0	N/A	5.17-15.6	10.3-14.4	4.75-12.0
Glaciolacustrine	5.42-8.17	11.25	13.1	8.42-10.3	6.83-7.0
Range of pH	K4.6	K4.8	K4.10	K4.12	K4.15
Upper loess upper 50 cm	6.7-7.9	7.1-8.3	7.3-8.2	7.3-7.8	7.0-7.8
Upper loess below 50 cm	7.8-8.3	7.85-8.45	8.2-8.5	7.9-8.4	7.85-8.7
Lower loess	8.1-8.3	N/A	8.0-8.2	8.3-8.4	7.7-8.1
Glaciolacustrine	7.7-8.0	8.0	7.9	7.75-8.1	7.8-8.1

Table 6.2. Range of calcium carbonate content (%) and pH for K4.6, K4.8, K4.10, K4.12, and K4.15.

The four fields within the diagram now can be addressed. The low pH - high carbonate field contains no data points, for the obvious reason that high carbonate content is chemically incompatible with low pH. Samples within this field likely contain significant amounts of primary carbonates. These are minimally weathered materials. In contrast, the high pH - high carbonate field contains a significant number of samples. Obviously samples with high calcium carbonate must have relatively high pH values. Samples from the high pH - low carbonate field likely have experienced loss of primary carbonates, but they also contain secondary carbonates sufficiently well dispersed through the groundmass to generate a pH of 8 or more. The two latter fields include most of the samples from the upper loess from depths greater than 50 cm, and six samples from the upper loess, from lesser depth. They also contain several samples from the lower loess.

The fourth field, with low pH and low carbonate, is the most interesting one because it includes those materials that, on the basis of these two properties, would be regarded as the most weathered. This field includes most samples from the control zone that is within common depth of the rooting of native perennial plants. They have been partially decalcified, but also partially recalcified, from redistributed freshly supplied carbonates. The most interesting occupants of this field are 8 samples from the

lower loess, all of them from station K4.15. From Figure 6.1e, it can be seen that these samples are located below the bulge of secondary carbonates that typifies the basal increment of the upper loess at this site. These samples are from a stack of paleosols that must have been decalcified prior to partial, postburial recalcification. These samples occupy the same field as the relatively modern samples, but they probably were severely if not completely decalcified prior to partial postburial recalcification. Probably, the modern samples will become further alkalized as they become buried to greater depth.

6.2 Comments on lateral soil variability

Soil-landscapes with a relatively stable land surface can reveal systematic patterns of spatial variability, especially when analyzed along hillslopes. These patterns normally are attributed to effects of slope on processes of infiltration, surface runoff, erosion and deposition, and effects of wetness and exposure on plant productivity (Birkeland 1984). Although soil-slope relationships were not evaluated during this study, several observations need to be summarized.

Organic carbon content from control sections from the upper 50 cm at the sites in table 6.1 were higher in low landscape positions than farther upslope. This was attributed to differences in soil wetness (section 6.1ci). The

associations between organic content and soil darkness also differs from one core station to the next, to the extent that, when considered at comparable organic content, the materials at lower positions are darker than those farther upslope. These observations suggest that, along this slope, soil organic matter does not only vary in quantity, but also in terms of quality.

6.3 Evolution of soils through postglacial times

The first soil-forming interval recorded at the Kipp site occurred during deposition of the lower loess. This interval occurred sometime after 11.2 ka. But before deposition of the upper loess began ca. 9 ka, two soils already had been buried by the lower loess, and another had formed in its top part. This indicates that shortly after 11.2 ka, environmental conditions were conducive to increased soil formation. The mode of origin of these soils was not necessarily similar to that of modern soils, because the conditions under which they formed were not necessarily comparable. Results from this study suggest that their organic carbon contents and colour were modified as a result of postburial change, so that these criteria cannot be used for pedogenic interpretation. Carbonate contents and pH values for these buried soils probably attained their present-day values in ways that involved postburial redistribution of soluble constituents and that were not comparable to what has happened so far in modern

soils. Another reason why it will remain difficult to interpret the facies of these soils is that they predate the onset of the Hypsithermal. The onset of this climatic interval was placed ca. 9180 BP by Lichti-Fedorov (1970) and ca. 9000 BP by Harris and Pip (1973). Pre-9 ka pollen assemblages from central Alberta are unlike those from extant vegetation associations, so that climate transfer functions are not applicable to them (Vance 1986). This may mean that the genesis of soils from the lower loess complex was governed by a type of vegetation whose dynamics are enigmatic.

Soils that form part of the upper loess complex should be more comparable to those from the present-day soil continuum. They date from an interval, i.e. since 9 ka, with soil-forming factors, i.e. environmental factors including vegetation, that, according to palynologists, can be reconstructed from transfer functions based on present-day ecosystems (Vance 1986). Unfortunately, such transfer functions cannot yet be applied to southern Alberta, because suitable fossil records have not yet been located. The analytical characteristics obtained so far from the upper loess soils pre-empt direct comparisons with those from modern soils, because they were modified by postburial processes. Different soil characteristics will have to be used in future work to form a basis for evaluating postglacial soil evolution from frameworks such as the one at Kipp.

CHAPTER SEVEN
DISCUSSION AND CONCLUSIONS

7.1 Overview

This study has examined landscape evolution involving loess mantling of former lacustrine lake surfaces in southern Alberta. The sequence of events reconstructed for the last ca. 18 000 years is summarized in Table 7.1. At ca. 14 ka, Laurentide ice dammed glacial meltwater, resulting in the creation of Glacial Lake MacLeod. As the ice retreated to the northeast, Glacial Lake Lethbridge was created. With further ice retreat from this area, Glacial Lake MacLeod drained through Verdigris Coulee, followed by Glacial Lake Lethbridge through Etzikom Coulee. Deglaciation of the area was followed immediately by the onset of loess accumulation. This is indicated by the lack of a paleosol or soil-forming interval directly above the glaciolacustrine silts and clays that were likely deposited in the glacial lakes. By ca. 11.7 ka, the lower loess had begun to accumulate. At 11.2 ka, when Glacier Peak volcano erupted, the Oldman River had already incised 35 m below the MacLeod Plain and 50 m below the Lethbridge Plain. Accumulation of the lower loess continued, and shortly after 11.2 ka, the first soil complex began to form. At ca. 9 ka,

Chronological Summary of Glacial and Postglacial Landscape Events in Upland systems and Fluvial Systems of the Lethbridge Area								
Time ka	Glacial and Postglacial Landscape Events		Evidence from site records					
	Upland Systems	Fluvial Systems	VON	B	OC	Pop	Kipp	CP
Present	Cont. accumulation of upper loess alternating with soil formation	meander migration	X	X	X	X	X	X
6.8	Mount Hazama volcano erupts		X	X	-	-	X	X
	Cont. accumulation of upper loess alternating with soil formation	7 River incision shifts to lateral migration	X	X	X	X	X	X
ca. 7	Major cycle of carbonate Translocation		-	-	-	-	X	-
ca. 9	Incipient accumulation of upper loess alternating with soil formation	Further incision of Oldman River (Drainage of Lake Agassiz)	X	X	X	X	X	X
	Major change in aeolian regime							
	Local fluvial channel cycle		-	-	-	-	X	-
	First soil complex forms in lower loess							
	Accumulation of lower loess							
11.2	Glacier Peak volcanic eruption	Oldman River 35 m below MacLeod Plain, 50 m below Lethbridge Plain	X	X	X	-	X	X
	Accumulation of lower loess, without paleosols		X	X	X	(X)	X	X
ca. 11.7	Glacial retreat farther to NE	Incipient incision of Oldman River	X	X	X	X	X	X
	Incipient accumulation of lower loess without paleosols							
	Drainage of Lethbridge and MacLeod lake plain							
	Glacial retreat to position NE of Lethbridge creates Glacial Lake Lethbridge (MacLeod remains submerged)	Drainage through Etzikom Coulee	X	X	X	X	-	-
14/13.5	Glacial readvance to position of Lethbridge moraine creates Glacial Lake MacLeod	Drainage through Verdigris Coulee	-	-	-	-	X	X
	Glacial retreat behind position of Lethbridge Moraine		X	X	X	X	X	X
ca. 18	Incipient Laurentide retreat from Late Wisconsin Terminus		-	-	-	-	-	-

Table 7.1. Chronological summary of glacial and postglacial landscape events in upland and fluvial systems of the Lethbridge area.

with continued incision of the Oldman River, a shift in the aeolian regime from a silt dominated loess to an upper, more sandy loess occurred. From ca. 9 ka onwards, accumulation of the upper loess continued with periods of increased soil formation.

The lower loess appears to have been deposited (or perhaps preserved) in swales or depressions in the deglaciated surface. This material apparently represents a distal facies from a source or sources unknown, possibly including the recently exposed lake plain. The upper loess, however, deposited by a new dispersal system appears to have been deposited on the smoother surface created by the lower loess. The upper loess has thickness and distribution patterns that are clearly related to a source located in the adjacent valley. A model is proposed to explain these spatial relationships. This involves airflow separation caused by the presence of a major obstacle, the valley bluff, and minor additional obstacles, the spurs or ridges at the top of this bluff. This model may explain the preferred accumulation of wind-blown material on the ridges and lesser accumulation in the intervening coulees, but it also explains why the thickest loess is nearer the bluff edge.

Loess accumulation clearly was cyclic and alternated with intervals of slower or no deposition, that permitted increased

soil formation. Average accumulation rates were calculated from time markers provided by tephra beds. Average rates are 0.4 mm/a for the lower loess and 0.29 mm/a for the upper loess. These rates do not make allowances for depositional hiatuses and slowdowns during soil forming intervals.

Three soil-forming intervals are represented in the lower loess at the Kipp site and twelve in the upper loess. Soils from the lower loess formed between 11.2 and 9 ka, under a type of vegetation that may not have a modern analog. Also, because of postburial change of their properties, it is difficult to compare them to modern soils. Soils from the upper loess developed since 9 ka, during the Hypsithermal and more recently, under conditions that likely have modern analogs, although they are presently uncertain. Soils in this unit also have experienced postburial change so that they cannot be directly compared to modern soils.

7.2 Limitations of the Study

A major limitation to the study was the lack of suitable outcrops in the Lethbridge area. This necessitated the use of boreholes made with a trailer-mounted hydraulic drill, which, as an advantage, allowed for exploration of the three-dimensional variability of the subsurface. The terrain of the study area dictated which parts could be accessed. Time constraints further restricted the number of boreholes that

could be made. As a result, the fairly large distances between boreholes prevent accurate correlations of individual units between stations.

Other limitations obviously arose from the fact that standard soil characteristics, such as organic carbon, calcium carbonate, pH, and colour, are modified upon burial. Nevertheless, those properties remain useful to differentiate between materials since they are standard criteria.

7.3 Suggestions for future research

This study has examined the evolution of a postglacial loess mantled area in southern Alberta. A next step would be to study the present-day aeolian processes. Wind traps could be set up at the Kipp site to monitor loess transportation rates, and determine present-day rates of loess accumulation. A study of this type could then be interfaced with the present study to determine the response of geomorphic and pedological processes to climate and environmental changes.

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APPENDIX A

Core descriptions

Table A1.

Stratigraphical Observations on VanderHeyden Site, near Picture Butte, Alberta. Main gully cut - east wall. Glacier Peak ash is traceable here for 9 m horizontally, before disappearing towards the north. Ash may extend further south, but access is impossible without ropes.

Depth (cm)	Unit	Observations
0 - 13	IAh	10 YR 4/3 (dl yl brn); sl; mod med sb, bk frequent roots; noncalc; abr bd.
13 - 25	Bm	10 YR 5/3 (dl yl brn); sl; mod med sb bk; com roots; calc; abr bd.
25 - 104	Bm2b1	10 YR 6/2 (gry yl brn); sl; mod med sb bk; calc; abr bd.
104 - 165	IIBmb2	10 YR 6/2 (gry yl brn); sl; mod med prism; calc with some sec carb in veins; abr bd.
165 - 254	IIIC	10 YR 6/2 (gry yl brn); sil; mass; contains Glacier Peak ash at approx. 200 cm below the surface; calc (ash noncalc); abr bd. <u>Note:</u> Glacier Peak ash was sampled and photographed.
254 -	IVC	10 YR 2/2 (brn black) clays alternating with 10 YR 6/3 (dl yl orange) silts; glaciolacustrine sequence; deformed (gentle folds); calc; abr bd. <u>Note:</u> There appears to be a thin stone line (2.5cm thick) 236 cm below the surface.

Table A1a
Stratigraphical Observations on Vanderheyden Site, near
Picture Butte, Alberta. Gully site east of dog bone site.

Depth (cm)	Unit	Observations
0 - 3	Ah	10 YR 5/3 (dl yl brn); sl (recent dust); mod fi platy; v frequent roots; noncalc; abr bd.
3 - 31	IAh	10 YR 3/3 (dk brn); sl; mod med sb bk; frequent roots; calc; abr bd.
31 - 64	Bm	10 YR 4/3 (dl yl brn); sl; mod co sb bk; frequent roots; calc; abr bd.
64 - 74	IIAhb1	10 YR 4/3 (dl yl brn); sl; mod med sb bk; frequent roots; calc; abr bd.
74 - 94	Bmb1	10 YR 5/4 (dl yl brn); sl; mod med sb bk; common roots; calc; abr bd.
94 - 135	Bmb2ca	10 YR 5/3 (dl yl brn); sl; mod med prism; v few roots; calc w ab s e c carb in veins and small patches; abr bd.
135 - 191	IIIBmb3	2.5 Y 6/3 (dl yl); sil; mass; calc w ab spk of sec carb in patches; abr bd.
191 - 234	IVC	10 YR 5/2 (gry yl brn); cl; mod co platy; calc; abr bd. (glaciolacustrine)
234 -	VC	10 YR 6/2 (gry yl brn) sil (2-3cm) alt w 10 YR 3/1 (brn black) cl (<1cm); calc; abr bd. (glaciolacustrine sequence)

Stratigraphy at the Van Der Heyden Borehole Site

Depth (cm)	Description
0 - 5 Ah	2.5Y 3/2 (very dark grayish brown); sandy loam; moderate fine granular; noncalcareous; distinct boundary;
5 - 20 IIAhb1	2.5Y 4/2 (dark grayish brown); sandy loam; strong coarse subangular blocky to moderate medium prismatic; noncalcareous from 5 to 10 cm, calcareous from 10 to 20 cm; distinct boundary;
20 - 40 IIBmb1	2.5Y 5/2 (grayish brown) with dark grayish brown ped coatings; sandy loam; strong medium to coarse prismatic; calcareous; distinct boundary;
40 - 58 IIBm2b1	2.5Y 5/2 (grayish brown); sandy loam; structure as above; calcareous; less distinct coatings on peds; abrupt boundary;
58 - 64 IIIBAb2	2.5Y 4/2 (dark grayish brown); sandy loam; moderate coarse subangular blocky; calcareous with secondary carbonates in faint veins; distinct boundary;
64 - 90 IIIBmca1 b2	2.5Y 4/4 (olive brown) with dark grayish brown (2.5Y 4/2) coatings on peds; sandy loam; strong medium and coarse prismatic; prominent but discontinuous lime coatings superposed on dark coatings on peds; few roots; gradual boundary;
90 -106 IIIBmca2 b2	2.5Y 5/4 (light olive brown); sandy loam; moderate coarse prismatic; weak secondary lime in veins; abrupt boundary;
106-116 IVCca	2.5Y 7/4 (pale yellow); loam; weak coarse subangular blocky; abrupt boundary;
116-144 VBmca3	2.5Y 5/2 (grayish brown) with weak slightly darker coatings on peds; loam; moderate medium prismatic; secondary lime on peds; many biopores; distinct boundary;
144-185 VIBmca3	2.5Y 6/4 (light yellowish brown) with grayish brown (2.5Y 5/2) coatings; moderate coarse prismatic; secondary lime in weak veins; abrupt boundary;
185-204 VIIIBmb4	2.5Y 5/3 (grayish brown to light olive brown) with dark grayish brown coatings; loam; moderate coarse subangular blocky to moderate fine prismatic; distinct boundary;
204-250 VIIIBmca b4	2.5Y 5/4 (light olive brown) with discontinuous grayish brown coatings; loam with faint horizontal partings; moderate to strong prismatic; thick secondary lime in veins; distinct boundary;
250-348 VIIC	2.5Y 6/4 (light yellowish brown); loam with faint horizontal lamination and in places with weak medium subangular blocky pseudostructure; zone of secondary lime from 312 to 318; abrupt boundary;
348-436 VIIIC	interbedded black (2.5Y 3/0) clay and light olive brown (2.5Y 5/4) silt loam layers; glaciolacustrine rhythmites; <u>clay layers</u> : 348-354, 358-368, 378-383, and alternating with thin silt beds in 396-430; <u>silt layers</u> : 354-358, 368-378, 383-396, 430-436;
436-460 IXC	2.5Y 5/4 (light olive brown); gritty silt loam with fine (< 0.5 cm) gravel; diamicton; abrupt boundary;
460-460.5 XC	2.5Y 6/6 (olive brown); well-sorted medium sand; abrupt boundary;
460.5-480+ XIC	glaciolacustrine rhythmites, as described for 348-436.

Summary: The upper loams are sandy, from 0 to 250 cm, and the lower loams are more silty, from 250 to 348 cm. Below these are glaciolacustrine rhythmites. The dark stained zone that is clearly visible in Figure 4.1 is not recognizable from the drill core. Microscope analysis reveals the presence of two tephra beds, i.e. between 318 and 312 cm, and between 240 and 222 cm depth.

Table A2. Stratigraphical Observations on Barrons Site, West, near Picture Butte, Alberta. Located along the west side of gully cut at the beginning of the cut, near survey site #2.

Depth (cm)	Unit	Observations
0 - 8	IAh	10 YR 5/3 (dl yl brn); sl; mod med crumb; frequent roots; calc; abr bd.
8 - 31	Bm	10 YR 6/3 (dl yl orange); sl; mod med sb bk; com roots; calc; abr bd.
31 - 41	IIAhb1	10 YR 4/3 (dl yl brn); sl; mod med sb bk; f roots; calc w abcsec carb in veins; abr bd.
41 - 48	Bmb1	10 YR 5/3 (dl yl brn); sl; mod fi sb bk; f roots; calc; abr bd.
48 - 53	IIIAhb2	10 YR 4/3 (dl yl brn); sl; mod med prism; v f roots; calc with some sec carb in veins; abr bd.
53 - 64	IVAhb3	10 YR 6/3 (dl yl brn); sil (ash?); mod med prism; v few roots; calc; abr bd. <u>Note:</u> Ash? Not like the ash layer in the east side of the cut. This layer is darker in colour and is not as powdery (silky) in texture?
64 - 84	VAhb4	10 YR 4/2 (gry yl brn); s cl loam; mod med prism; calc w ab sec carb in veins; abr bd.
84 - 99	VIAhb5	10 YR 3/2 (brw black); sil cl loam; mod med prism; calc w ab sec carb in veins; abr bd.
99 - 130	VIIAhb6	10 YR 2/2 (brw black); sil cl loam; mod med prism; calc; abr bd.
130 - 175	Bm1b6	10 YR 5/3 (dl yl brn); sil cl loam; mass; cal; abr bd.
175 - 206	Bm2b6	10 YR 4/3 (dl yl brn); sil cl loam; mass; calc; abr bd.
206 - 224	VIIIIC	10 YR 4/3 (dl yl brn) sil alternating w 10 YR 2/2 (brn black) cl; calc; abr bd. (glaciolacustrine silts and clays)

Summary:

0 - 64cm	loess
53 - 64	ash?
64 - 130	paleosol
130 - 206	transition?
206 - 224	glaciolacustrine silts and clays

Table A3. Stratigraphical Observations for Diamond City Site, near Diamond City, Alberta. North side cut along road; far north side of gullied region. No ash visible.

Depth (cm)	Unit	Observations
0 - 15	IAh	10 YR 4/3 (dl yl brn); sl; mod med crumb; frequent roots; noncalc; abr bd.
15 - 31	Bm	10 YR 4/4 (brn); sl; mod f sb bk; common roots; calc; abr bd.
31 - 109	IIBmb1	10 YR 6/3 (dl yl orange); sl; mod med sb bk; calc; slight dark staining on the peds; abr bd.
109 - 168	IIIC	10 YR 4/2 (gry yl brn) cl alt w 10 YR 6/3 (dl yl orange) sil; calc (clays are weakly calc); glaciolacustrine sequence; shows some deformation (gentle folds); abr bd.
168 - 285	IVC	10 YR 6/3 (dl yl orange); s sil loam; mass; wk calc; contains some pebbles, stones, and cobbles (>1 cm to <20 cm).

Note: No shells were noted.

Sampled taken at 216cm, possibly ash?

Summary:

0 - 109	loess
109 - 168	glaciolacustrine
168 - 285	diamicton?

Table A4. Stratigraphical Observations on Popson Park Cut, near Lethbridge, Alberta. Located at far north high point in park.

Depth (cm)	Unit	Observations
0 - 15	fAh	10 YR 5/3 (dl yl brn); sl; mod f sb bk; v frequent roots; noncalc; abr bd.
15 - 23	Bm	10 YR 4/3 (dl yl brn); sl; mod med sb bk; frequent roots; noncalc; abr bd.
23 - 33	IIAhb1	10 YR 4/2 (gry yl brn); sl; mod med sb bk; common roots; noncalc; abr bd. <u>Note:</u> A thin stone line (3 - 5 cm) was noted at a depth of 28 - 33 cm. No shells were noted.
33 - 53	Bmb1	10 YR 4/3 (dl yl brn); sl; mod med prism; com roots; noncalc; slight dark staining on the peds; abr bd.
53 - 84	Bmb2	10 YR 5/3 (dl yl brn); sl; mod co prism; f roots; noncalc; slight dark staining on the peds; abr bd. <u>Note:</u> This layer also contained a few, random, small (<1 cm) stones (pebbles). No shells were noted.
84 - 94	Bmb3	10 YR 5/2 (gry yl brn); sl; mod co prism; v few roots; calc; abr bd.
94 - 127	III Ahb2	10 YR 4/1 (brn gry); s (sil) loam; mod med sb bk; v f roots; calc w ab sec carb in large patches and along veins; abr bd. <u>Note:</u> This layer also has a few random stones (pebbles) 1-4 cm in size scattered throughout the layer. No shells were noted. <u>Note:</u> This layer is a dark paleosol that extends along most of the cut before wedging out at both ends. (Bulk sample taken).
127 - 241	IVC	2.5 Y 6/3 (dl yl); sl; mass; calc w ad sec carb in veins; abr bd. <u>Note:</u> This layer also contains some random stones and cobbles (1-10 cm). No shells were noted.
241 - 287	VC	2.5 Y 4/4 (olive brn); sil cl loam; mass; some cl nod noted (1 cm); calc; abr bd. (transition?)
287 - 439	IVC	10 YR 4/1 (brn gry) cl (1 cm) alternating w 10 YR 4/3 (dl yl brn) sil layers (13-15 cm); calc; abr bd (glaciolacustrine)

Table A5. Stratigraphical Observations on Airport Site, Stewart land, Lethbridge, Alberta. Cut bank observations along north side of NW - SE trending coulee.

Depth (cm)	Unit	Observations
0 - 10	IAh	10 YR 5/3 (dl yl brn); sl; mod med sb bk v frequent roots; calc; abr bd.
10 - 20	Bm	10 YR 5/3 (dl yl brn); sl; mod med prism; frequent roots; calc; abr bd.
20 - 23	IIAhb1	10 YR 5/2 (gry yl brn); sl; mod med sb bk; com roots; calc, abr bd.
23 - 36	Bmb1	10 YR 4/3 (dl yl brn); sl; mod med sb bk; few roots; calc; abr bd.
36 - 38	III Ahb2	10 YR 4/2 (gry yl brn); sl; mod med sb bk; f roots; calc; abr bd.
38 - 94	Bmb2	10 YR 5/2 (gry yl brn); sl; mod med sb bk; v f roots; calc w frequent sec carb in veins; ab shells (types to be identified); many small stones (pebbles) interspersed throughout this layer; abrupt boundary. <u>Note:</u> two bulk samples were taken from this layer to be later sifted to separate the shells for identification and possible dating. (Possibly to be separated using sonic dispersal methods.)
94 - 366	IVBmb3	10 YR 5/3 (dl yl brn); sl; mass; many small stones throughout the layer; few shells; calc; abr bd. <u>Note:</u> stone and cobble size from 1 mm to 15 cm; there was no definite layering; layer shows vertical and horizontal jointing; some carbonates in patches; some charcoal patches. <u>Note:</u> below loess at a depth of 3 - 3.65 m, bedded silt and clays, clay layers about 1 cm in thickness, silt layers about 10cm thick; possibly silt aeolian deposited or rhythmites.

Description Pit A, Stop 1

Unit I. (0.5 m exposed). Fluvial gravels with Laurentide clasts. The gravel surface has swell-swale topography with a local relief estimated at 2 m. Swells on gravel surface are directly and abruptly overlain by unit III (loess). Swales are filled with material from unit II (fluvial sands), directly on gravels.

Unit II. (Maximally 0.9 m). Fluvial sands of swale infilling. Planar-bedded medium and coarse sand, with minor low-angle crossbedded sand units, apart from several discontinuous bands (1 cm) of very fine gravel (< 8 mm).

A tephra bed (Glacier Peak ?) is intercalated 35 cm beneath the top of Unit II and is overlain by planar laminated medium sand. The tephra bed is composed of white silt-size glass grains and is maximally 1 cm thick. The bed was traceable over about 10 m along the northern exposure, but it was not found along the southern exposure.

The upper 35 cm of unit II has planar lamination and the contact with the basal laminated increment of unit III (loess) is gradational. Possibly the upper part of unit II is of eolian origin. Regardless of this, it appears that aeolian deposition directly followed accumulation of the last fluvial increment or was contemporaneous with it.

Unit III. (3.5 m). Loess with three subunits: IIIA: Basal Loess (1.5 m); IIIB: Tephra Bed (10 cm); IIIC: Upper Loess (2.4 m).

Subunit IIIA: Max. 1.5 m thick, but thinning to 0.8 m above swells on gravel substrate. Sandy loam, massive except for lowermost 0.5 m which has faint horizontal lamination. No discernible buried soils, apart from a slightly darker-stained vague zone (0.5 m thick) beneath subunit IIIB.

Subunit IIIB: 0.1 m thick. Sandy loam with pods of white silt, composed of volcanic glass (Mazama ?). This unit is traceable along both the northern and southern exposure of the trench.

Subunit IIIC: From 2.0 to 2.4 m thick. Sandy loam, devoid of discernible buried soils. Culminates with solum of groundsoil.

Description Pit B, Stop 1 (North side)

Unit I. (2+ m exposed). Fluvial gravels

Unit II. (1.2 m). Sand. Massive, possibly eolian.

Unit III. (0.8 m). Loess. Sandy loam.

Unit IV. (0.5 m). Fluvial Gravel. Wedge-shaped unit, probably a gravel bar deposit. Cross-bedded, where thickest (0.5 m), and planar-bedded where it is thinnest (0.1 m) and sandy and contains a bone.

Table 1. Stratigraphical Observations on AgCan Site near Kipp, Alberta.

Depth(cm)	Unit	Observations
2 - 0	0	10YR 5/4 (yellowish brown); fine sandy loam (recent dust);
0 - 23	I	10YR 4/4 (yellowish brown); Ah and Bm combined; sandy loam; very weak subangular blocky; calcareous; common roots; abrupt smooth boundary;
23 - 47	II	10YR 4/2 (dark grayish brown); Ah (23-29 cm) on yellowish brown, weak subangular blocky to prismatic Bm; loam to sandy loam; calcareous; abrupt boundary;
47 - 98	III	10YR 4/3 (yellowish brown); AB (47-49 cm) on Bmca grading into Ck; sandy loam; calcareous with secondary carbonate specks on vertical cleavages; abrupt boundary;
98 -122	IV	10YR 4/3; Ah (98-103 cm) on Bmca; sandy loam; carbonates as above; abrupt boundary;
122-164	V	10YR 4/4; Bm (122- 137 cm) on BC; sandy loam; carbonates as above; abrupt boundary;
164-221	VI	10YR 4/4; Bm (164-190 cm) on Ck; sandy loam; calcareous with secondary carbonates; abrupt boundary;
221-285	VII	10YR 4/4; Bm (221-232 cm) on Ck; sandy loam; calcareous with flecks of secondary carbonates; abrupt boundary;
285-322	VIII	10YR 4/4; Bm (285-295 cm) on Bca (295-305 cm) on Ck; sandy loam; secondary carbonates; abrupt boundary;
322-372	IX	10YR 4/4; BA (322-327 cm) on Bm (327-360 cm) on Ck; sandy loam with very fine sand layer (360-362 cm); abrupt bd;
372-470	X	10YR 4/4; Bm (372-412 cm) on Ck; sandy loam; weak dark coatings and carbonate flecks on planes; abrupt bd;
470-565	XI	10YR 4/4; Bm (470-485 cm) on Bmca (485-515 cm) on Ck; sandy loam; abrupt boundary;
565-608	XII	Black cumulic Ah (565-595 cm) on AB (595-600 cm) on Bm (600-608 cm); sandy loam; secondary carbonates in veins; abrupt boundary;
608-671	XIII	Black cumulic Ah (608-624 cm) on Bm; sandy loam; end.

1. Located on AgCan upland, 100 m south of westernmost powerline pole.
2. Cored with Giddings and described on August 27, 1987, by W.J. Vreeken and R. Barnes. Deeper coring prevented by denseness of material.
3. Buried soils at 565 and 608 cm appear mucky and could indicate presence of perching glaciolacustrine sediment slightly deeper down.

Stratigraphy at the Kipp Kl.2 Borehole Site

Depth (cm)		Description
0 - 17	Ah	2.5Y 4/4 to 5/4; sandy loam; moderate to weak fine to medium subangular blocky; calcareous; abrupt boundary;
17 - 29	IIAhb1	2.5Y 4/2; sandy loam; moderate to strong medium subangular blocky; noncalcareous; abrupt boundary;
29 - 45	IIBAb1	2.5Y 4/4; sandy loam; weak medium subangular blocky with weak fine to medium prismatic overprint; calcareous; abrupt boundary;
45 - 65	IIBm1b1	2.5Y 4/4 to 5/5; same as above; abrupt boundary;
65 -115	IIBm2b1	2.5Y 5/4; sandy loam; moderate to weak medium and fine prismatic; calcareous with secondary lime mycelium.
115		Coring blocked probably by stones

Comment: This site is on a narrow, level interfluvial, several metres west of the entrance to the L.U.L.U. complex. Elevation: 930 m asl. Outcrops of glaciolacustrine sediments are within several scores of metres. On narrow interfluvials, those sediments often have a thin wind pavement composed of dropstones at the top. This may have blocked further coring. The lower, i.e. silty, loess is not represented in the core and may be missing owing to erosional hiatus.

Table K2.1. Stratigraphical Observations on AgCan Site, near Kipp, Alberta. Drill Core #K2.1 located in NE corner of first field (Drill core #1.1) on loess capped crest.

Depth	Horizon	Observations
000-005	IAh	10 YR 5/3; sl; mod med crumb; calc; abr bd;
005-028	Bm	10 YR 5/3; sl; mod med sb bk to wk mod prism; calc; abr bd;
028-071	IIAhb1 + Bm1b1	10 YR 4/3; sl; mod med sb bk to wk med prism; calc; abr bd;
071-145	Bm2b1	10 YR 5/4; sl; mod med sb bk to prism; calc; abr bd;
145-201	IIIAhb2+ Bmb2	10 YR 5/4); sl; mod med sb bk to wk prism; calc w f sec carb in veins; abr bd;
201-216	Bm2b2	10 YR 5/4; sl; mod med sb bk; calc w ab sec carb in veins; abr bd;
216-348	IVAhb3+ Bmb3	10 YR 5/3; sl; mod med sb bk; calc; slight dk staining on peds; abr bd;
348-358	VAhb4	10 YR 5/2; sl; mod med sb bk to wk prism; calc; abr bd;
358-386	Bm1b4	10 YR 5/3; sl; mod med sb bk; calc w sec carb in veins and random spk or patches; slight dark staining on peds; abr bd;
386-462	Bm2b4ca	10 YR 4/3; sl; mod med sb bk; calc w ab sec carb in veins; slight dark staining on peds; abr bd;
462-533	VIBm3b4	10 YR 5/3; sl; mod med sb bk to wk med pris; calc w f sec carb in veins; abr bd.

Summary: 0 - 533 cm loess

Note: 533 cm cored. Material getting dense at 533 cm. Unable to core further because anchor was pulled loose from finer loess at top at 533 cm.

Stratigraphic observations at station K2.2, Kipp area.

Depth	Horizon	Description
000-005	Ah	2.5Y 4/3; sal (recent dust); mod fi crumb; calc; abr bd;
005-024	Bm	2.5Y 5/4; sal; mod fi sb bk; calc; abr bd;
024-035	IIAhb1	2.5Y 4/2; sal; str fi sb bk; calc; abr bd;
035-055	IIBmb1	2.5Y 5/2; sal; str fi sb bk; calc; abr bd;
055-064	IIIAhb2	2.5Y 4/2; sal; str fi to med sb bk; calc; abr bd;
064-080	IIIBmb2	2.5Y 4/4; sal; str fi prism w mod fi sb bk; thin org coatings on vert cleavages; calc; abr bd;
080-088	IVAhb3	2.5Y 5/2; sal; mod fi sb bk; calc w fi sec lime spk; abr bd;
088-260	IVBmb3	2.5Y 5/4; sal; wk fi sb bk; calc w sec lime fil; "giant" eolian-cumulic B horizon; abr bd;
260-312	VABb4	2.5Y 5/2; sil; wk fi sb bk; biochannels; calc; abr bd;
312-360+	VIC	Clay-and-silt rhythmites, dom by clay; fi sb bk pseudostructure; calc; glaciolacustrine.

Stratigraphic observations at station k2.3, Kipp area.

Depth	Horizon	Description
000-015	Ah	10YR 4/3; sal; str fi sb bk (crumb in upper cm); calc; abr bd;
015-045	Bmca	2.5Y 5/4; sal; mod fi bk w mod fi prism; calc w some sec lime in fil on peds; abr bd;
045-058	IIAhBm1b1	2.5Y 4/4; sal; mod fi sb bk w wk platiness (bedding?); calc w sec lime veins; abr bd;
058-069	IIBm2b1	2.5Y 5/4; sal; mod fi sb bk; calc w common sec lime veins (<1/2 cm thk); abr bd;
069-082	III Ahb2	2.5Y 3/2; sal; mod v fi sb bk; calc w common sec lime veins (<1/2 cm thk); abr bd;
082-104	IIIBmb2	2.5Y 5/4; sal; wk fi sb bk; calc w f sec lime; abr bd;
104-108	IV Ahb3	2.5Y 5/2; fi sal; wk fi sb bk; calc w v f sec lime; abr bd;
108-114	IVBmb3	2.5Y 5/4; fi sal; v wk fi sb bk; calc; abr bd;
114-120	VAhb4	2.5Y 4/2; fi sal; wk v fi sb bk; calc; vv abr bd;
120-124	VIC	2.5Y 6/4; sil; single grain; calc; tephra bed; abr bd;
124-133	VII Ahb5	2.5Y 4/2; fi sal; wk fi sb bk; biopores, calc; abr bd;
133-165	VII Bmb5	2.5Y 6/4; fi sal; wk fi sb bk; calc w mny fi sec lime flecks in 133-141 cm; abr bd;
165-175	VIII Ahb6	2.5Y 4/2; fi sal; wk fi sb bk; calc; abr bd;
175-213	VIII Bmb6	2.5Y 6/4; fi sal; wk fi sb bk; calc w f sec lime sp; abr bd;
213-240+	IXC	Clay-and-silt rhythmites; calc; glaciolacustrine.

Table K2.4. Stratigraphical Observations at Kipp, Station K2.4

Depth	Horizon	Description
000-015	Ah	2.5Y 3/2; sal; str med sb bk; noncalc; v hard; abr bd;
015-030	Bm	2.5Y 4/4; sal; str med sb bk to str fi prism; calc; abr bd;
030-069	IIBmb1	2.5Y 4/3 to 4/4; sal; str fi sb bk @ str fi prism; calc w sec lime myc; abr bd;
069-180	IIIBmb2	2.5Y 4/4; sal; str fi sb bk @ str fi prism; dark (2.5Y 4/2 @ 4/3 coatings on prisms; calc w sec lime myc @ fil; "giant" eolian-cumulic B horizon; abr bd;
180-226	IVBmb3	Same as above, but w slightly darker coatings below 180 cm; structure weakening w depth; abr bd;
226-229	VC	2.5Y 7/2; silt; calc; tephra bed; abr bd;
229-252	VIC	2.5Y 5/4; sal; massive; calc; abr bd;
252-256	VIIC	2.5Y 7/2; silt; calc; tephra bed; abr bd;
256-272	VIIIC	2.5Y 4/3; fi sal, less gritty than 252-256; v wk fi sb bk to massive; rel moist; calc; abr bd;
272-316	IXC	2.5Y 4/4; fi sal grading downwards to silt loam; massive; calc; abr bd;
316-317	XAhb4	2.5Y 3/2; sil; massive; calc; abr bd;
317-335	XBmb4C	2.5Y 4/4; sil; v wk fi sb bk to massive; calc; abr bd;
335-347	XIAhb5	2.5Y 4/2 to 4/3; sil; wkly platy or laminated; calc; abr bd;
347-367	XIBmb5	2.5Y 5/4, common fi gr brn and str brn mottles; sil; calc; abr bd;
367-380	XIIAhb6	2.5Y 3/2; sicl; wk fi platy to massive; calc; abr bd;
380-392	XIIBmb6	2.5Y 4/2; sicl; fi platy (lam?) to massive; calc; abr bd;
392-402	XIIIAhb7	Same as 367-380 cm; abr bd;
402-411	XIIIBmb7	Same as 380-392 cm; moist; abr bd;
411-453	XIIIC	2.5Y 4/4; sil, fi laminated; calc; moist; abr bd;
453-480+	XIVC	2.5Y 4/2; clay; mod fi sb bk pseudostructure; glaciolacustrine.

Table 3.1 Stratigraphical Observations near the Gynkhana Site, Kipp, Alberta

Depth, cm	Horizon	Observations
0 - 9	IAh/2m	10YR 5/4 (yellowish brown); sandy loam; very weak coarse prismatic and distinct coarse pseudoplaty; calcareous; common roots; abrupt smooth boundary;
9 - 11	IIAhb1	10YR 4/2 (dark grayish brown); loam to sandy loam; very weak fine subangular blocky; calcareous with white secondary carbonates; common roots; distinct smooth boundary;
11 - 20	IIBCab1	10YR 5/4 (yellowish brown); loam; moderate medium prismatic; calcareous with prominent white secondary carbonates on vertical cleavages; common roots; gradual boundary;
20 - 32	IIBCa2b1	10YR 5/4 (yellowish brown) to 2.5Y 4/4 (olive brown); loam; strong medium prismatic; faint horizontal bedding; calcareous with strong accumulation of secondary carbonate on vertical cleavages and some on horizontal cleavages; common roots; abrupt smooth boundary;
32 - 40	IIIAhb2	2.5Y 4/2 (dark grayish brown); loam; weak fine subangular blocky with very faint fine pseudoplatiness; calcareous with prominent secondary carbonates on vertical planes, originating from overburden; distinct smooth boundary;
40 - 59	IIIBCab2	2.5Y 4/4 (olive brown); loam; moderate medium prismatic; faint horizontal lamination; calcareous with secondary carbonates on vertical cleavages, and in vertical veins in lower 10 cm; few to common roots; abrupt smooth boundary;
59 - 69	IVAhb3	2.5Y 4/2 (dark grayish brown); loam; very weak fine subangular blocky; calcareous with secondary carbonates in vertical branching veins; distinct smooth boundary;
69 - 89	IVBCab3	2.5Y 4/4 (olive brown); loam; weak to moderate coarse prismatic; carbonates as above; abrupt smooth boundary;
89 - 91	VAhb4	2.5Y 4/2 (dark grayish brown); loam; massive; carbonates as above; distinct smooth boundary;
91 - 100	VBCab4	2.5Y 4/4 (olive brown); loam; weak to moderate coarse prismatic; calcareous with secondary carbonates in vertical branching veins; abrupt smooth boundary;
100-107	VI Ahb5	Same as VAhb4; faint horizontal lamination; distinct smooth boundary;
107-128	VIBCab5	Same as VBCab4, but seemingly less secondary carbonates; very abrupt smooth boundary;
128-131	VII Ahb6	2.5Y 3/2 (very dark grayish brown) in places black; loam; massive; calcareous with secondary carbonates in veins; fine charcoal specks; abrupt boundary;
131-132	VIIIBCab6	2.5Y 5/2 (grayish brown with pinkish cast); loam; massive; calcareous with secondary carbonates; distinct boundary; (possibly pyrogenically modified material);
132-165	VIIIBCab6/Cca	2.5Y 5/4 (light olive brown); loam; very weak coarse prismatic grading to massive at about 150 cm; prominent horizontal lamination, especially below 140 cm; calcareous with secondary carbonates in veins; distinct smooth boundary;
165-200†	VIIIC	Complex of alternating 2.5Y 5/4 (light olive brown) and 2.5Y 6/4 (light yellowish brown) loams layers; layers are internally laminated and range in thickness from 4 to 8 cm; pedologically massive; calcareous with very few secondary carbonates in veins; end of excavated sequence.

Stratigraphic Observations at Station K3.2, Kipp area.

Depth	Horizon	Description
000-004	Ah	Sandy loam w wk Ah in sod; calc;
004-009	IIC	Fine sand; loose; calc;
009-015	IIIC	Very sandy loam; massive;
015-140	IVC	Sand and loamy sand; no evidence of any significant pedogenesis; calc;
140-177	VC	Sandy loam with intercalations of medium to coarse faintly bedded loamy sand; cohesive; calc;
177-455	VIBmb1	Sandy loam; top of "giant" Bmb; mod fi prismatic with mod fi sb bk; calc w sec lime in specks and fil; moderate colloid coatings on vertical cleavages;
455-465	VIIIBmb2/C	Fine sandy loam to silt loam; calc; possibly containing ash (sampled);
465-500	VIIIIBmb3	Same as 177-455; calc; abrupt bd;
500-700+	IXC	Silt-and-clay rhythmites; massive; calc.

Stratigraphy at the Kipp K3.3 Borehole Site

Depth (cm)			Description
0 - 2	Ah		2.5Y 6/4; sandy loam; weak fine crumb; calcareous; common roots; common bare spots in grass cover; recent dust; abrupt boundary;
2 - 15	IIAhb1		2.5Y 4/4 to 4/2; sandy loam; weak fine subangular blocky to massive; calcareous, abrupt boundary;
15 - 68	IIBmb1		2.5Y 5/4; sandy loam; weak coarse subangular blocky and weak medium prismatic; calcareous, few fine lime specks; abrupt boundary;
68 - 80	IIIABb2		2.5Y 4/4; sandy loam; strong fine prismatic and moderate medium subangular blocky; calcareous, many fine lime specks and common lime mycelium; abrupt boundary;
80 -155	IIIBmb2		2.5Y 5/4; sandy loam; same as 60 - 80; giant B horizon; abrupt boundary;
155-173	IVBmb3		2.6Y 5/4; very sandy loam; moderate medium and coarse subangular blocky; calcareous with fine gypsum veins; abrupt boundary;
173-195	VBC		2.5Y 6/4; silt loam to fine sandy loam; weak fine subangular blocky to massive; calcareous; abrupt boundary;
195-205	VIBC		2.5Y 4/4 and 6/4, intermixed domains; silt loam; moderate coarse subangular blocky pedostructure and pseudostructure; modified silt and clay rhythmities; distinct boundary;
205-240+	VIC		glaciolacustrine rhythmities.

Summary: Sandy loam loess (0 - 173 cm) on silt loam loess (173 - 195 cm), on glaciolacustrine rhythmities, the upper 10 cm of which have been pedogenically altered.

Stratigraphy at the Kipp K3.4 Borehole Site

Depth (cm)			Description
0 - 4	Ah		2.5Y 4/4; sandy loam; noncalcareous; abrupt boundary;
4 - 15	BC		2.5Y 5/4; sandy loam; calcareous; abrupt boundary;
15 - 47	IIBmb1		2.5Y 4/4; sandy loam; calcareous; abrupt boundary;
47 - 58	IIIABb2		2.5Y 4/4; sandy loam; calcareous; abrupt boundary;
58 - 67	IVAhb3		2.5Y 4/2; sandy loam; calcareous; abrupt boundary;
67 - 77	IVBAb3		2.5Y 4/4; sandy loam; calcareous; abrupt boundary;
77 - 192	IVBmb3		2.5Y 5/4; sandy loam; calcareous; giant B horizon; abrupt boundary;
192-227	VBmb4		2.5Y 4/3; sandy loam; calcareous; abrupt boundary;
227-272	VIBCb5		2.5Y 6/4; silt loam to fine sandy loam; massive apart from common worm casts; calcareous; abrupt boundary;
272-310	VIIC		Glaciolacustrine rhythmites.
310			Blocked by very stiff material.

Summary: Sandy loam loess (0 - 227 cm), on silt loam loess (27 - 272 cm), on glaciolacustrine rhythmites

Stratigraphy at the Kipp K3.5 Borehole Site

Depth (cm)	Description
- 5 Ah	Sandy loam; slightly calcareous;
5 - 28 IIBmb1	Sandy loam; slightly calcareous till 11 cm, calcareous below 11 cm;
28 - 70 IIIBmb2	Sandy loam; calcareous;
70 - 90 IVABb3	Sandy loa; calcareous;
90 -132 IVBCb3	Sandy loam, progressively silty downwards; calcareous;
132-165 VC	Silt loam; massive; calcareous.
165	Blocked by dry dense material.

Summary: Sandy loam loess (0 - 132 cm), on silt loam loess (132 - 165 cm), probably on glaciolacustrine sediments. There is no evidence of a buried soil that may have formed in the top part of the silt loam loess.

Stratigraphy at the Kipp K3.6 Borehole Site

Depth (cm)	Description	
- 10 Ah	2.5Y 4/4;	sandy loam; noncalcareous; abrupt boundary;
10 - 20	IIAhb1	2.5Y 3/2; sandy loam; noncalcareous from 10 to 11 cm, calcareous below 11 cm; abrupt boundary;
20 - 40	IIABb1	2.5Y 4/4; sandy loam, increasingly silty downwards; calcareous; abrupt boundary;
40 - 43	III Ahb2	2.5Y 3/2; silt loam; calcareous; distinct boundary;
43 - 50	IIIABb2	2.5Y 4/4; silt loam; calcareous; abrupt boundary;
50 - 53	IV Ahb3	2.5Y 3/2; silt loam; calcareous; abrupt boundary;
53 - 73	IVBmb3	2.5Y 4/4; silt loam; calcareous; abrupt boundary;
73 - 90	VBmb4	2.5Y 5/4; silt loam; very weak fine subangular blocky to massive; calcareous; abrupt boundary;
90 - 138	VC	2.5Y 5/4; silt loam; massive; calcareous; very hard and dry.
138		Blocked by very hard and dry material, probably glaciolacustrine clays.

Summary: Sandy loam loess (0 - 40 cm), on silt loam loess (40 - 138 cm), on glaciolacustrine sediments.

Stratigraphy at the Kipp K3.7 Borehole Site

Depth (cm)		Description
0 - 8	Ah1	2.5Y 4/2; sandy loam; weak fine subangular blocky to weak coarse crumb; noncalcareous; abrupt boundary;
8 - 28	Ah2	2.5Y 4/2; sandy loam; moderate to strong fine subangular blocky; calcareous; calcareous boundary;
28 - 43	AB	2.5Y 4/4; sandy loam with weak horizontal partings; moderate to strong medium subangular blocky; calcareous; abrupt boundary;
43 - 55	IIAhb1	2.5Y 3/2; sandy loam; moderate to strong medium subangular blocky with moderate to strong medium prismatic overprint; calcareous; abrupt boundary;
55 - 60	IIIAhb2	2.5Y 3/2 to 2/2; sandy loam; weak coarse subangular blocky to massive; calcareous; few fine secondary lime specks; abrupt boundary;
60 - 80	IIIBm1b2	2.5Y 4/2; sandy loam; weak fine subangular blocky with moderate medium prismatic overprint; few fine secondary lime specks; gradational lower boundary;
80 -133	IIIBm2b2	2.5Y 5/2; sandy loam; structure as above; calcareous, very few fine lime specks but groundmass has been impregnated with very fine secondary lime; abrupt boundary;
133-156	IVBC	2.5Y 6/2 to 7/2; silt loam; weak to moderate medium prismatic; highly calcareous with fine, massive, white flecks; possibly Mazama (?) tephra bed; abrupt boundary;
156-165	VBmb3	2.5Y 5/2 to 6/2; sandy loam; very weak medium subangular blocky; calcareous; abrupt boundary;
165-174	VIBmb4	2.5Y 6/4; sandy loam; weak medium subangular blocky; calcareous; abrupt boundary;
174-185	VIC	2.5Y 6/4; sandy loam; massive; abrupt boundary;
185-202	VIIAhb5	2.5Y 5/2; silt loam; weak fine subangular blocky; abrupt boundary;
202-215	VIIBCb5	2.5Y 5/2; silt loam; massive;
215		Stopped by very dense layer, likely glaciolacustrine sediments.

Summary: 0 - 185: sandy loam loess, probably with a Mazama tephra bed at 133-156; 185-215: silt loam loess; below 215: glaciolacustrine sediments from Glacial Lake MacLeod.

Stratigraphy at the Kipp K3.8 Borehole Site

Depth (cm)	Description
0 - 80	Sandy loam loess, apparently devoid of buried soils.
80	Blocked by stiff dense material, none of which was collected in the core sampler.

Summary: Sandy loam loess (0 - 80 cm) on substrate probably composed of glaciolacustrine sediments.

Table JA. Stratigraphical Observations at the Kipp Site.

Depth (cm)	Description
0 - 53 IC	2.5Y4/4; loam, weak fine subang blocky; friable; weak eff; abrupt bd;
53 - 60 IIAb1	2.5Y3/3; loam to silt loam; weak fine subang blocky; friable; weak eff; grad bd;
60 - 80 IIC	2.5Y4/3; loam with sandy loam (2.5Y6/4) in basal 5 cm; weak fine subang blocky; friable; vig eff; abrupt bd;
80 - 90 IIIAb2	2.5Y3/3; loam; moderate fine to medium subang blocky; firm; very weak eff; grad bd;
90 -110 IIIBb2	2.5Y4/3; silt loam; moderate medium subang blocky; firm; weak eff; abrupt bd;
110-148 IVC	2.5Y4/3; sandy loam; very weak medium subang blocky; friable; vig eff; abrupt;
148-152 VABb3	2.5Y3/3; sandy loam; weak fine subang blocky; friable; vig eff; grad bd;
152-178 VBb3	2.5Y4/3; sandy loam; black stained horizontal partings; weak fine subang blocky to weak fine prismatic; friable; vig eff; grad bd;
178-198 VC	2.5Y4/3; loam; horizontal partings; very weak fine subang blocky to massive; friable; vig eff; abrupt bd;
198-240 VIBb4	2.5Y4/3; loam; weak fine prismatic to massive; friable; vig eff; grad bd;
240-350 VIC	2.5Y4/3; loam; dark horizontal partings; very weak coarse prismatic grading into massive; friable; grad bd;
350-370 VIIBb5	2.5Y3/2.5; loam (top of lacustrine sediments); very weak fine to medium subang blocky; friable; grad bd;
370-386 VIIBC	2.5Y4/3; occasional prominent medium mottles (10YR5/8 to 7.5YR5/8); sandy clay loam and silty clay; very weak medium subang blocky to massive; grad bd;
386-425 VIIC	2.5Y4/3 and 10YR5/1 in 50-50 % mottled mass; faint indications of preferred horizontal colour banding; silty clay; weak fine subang blocky to massive; slightly plastic; abrupt bd;
425-600+ IXC	2.5Y4/3; silty clay; weak to moderate fine subang blocky pseudostructure; plastic; fine crystalline gypsum seams at 437 and 440 cm; lacustrine sediments. End of core.

Hillcrest Site cored with Giddings in roadside ditch. Cored and described, on Aug. 9, 1983, by W.J. Vreeken and D.J. Pennock. Notes: Original upper 90 cm were not retrieved and zero depth is therefore 90 cm beneath original ground-surface. Bulk samples were generally obtained at 15 cm interval, unless necessitated otherwise on stratigraphical grounds.

Stratigraphic Observations at station K4.2, Kipp area.

Depth	Horizon	Description
000-008	Ah	Sandy loam; calc;
008-021	Bm	Very sandy loam to loamy sand; calc;
021-027	IIC	Fine sand; calc;
027-030	IIIAhb1	Very sandy loam; calc;
030-037	IIIBmb1	Very sandy loam; calc;
037-039	IVAhb2	Very sandy loam; calc;
039-045	IVBmb2	Very sandy loam; calc;
045-054	VAhb3	Sandy loam; calc;
054-086	VBmb3	Sandy loam; calc;
086-092	VIAhb4	Sandy loam; bleached surfaces of prismatic peds; calc;
092-105	VIBmb4	Sandy loam; calc;
105-120	VIIAhb5	Sandy loam; calc;
120-128	VIIIBmb5	Sandy loam; 2.5Y 4/4; mod fi sb bk; top of "giant" Bmb; calc;
128-135	VIIIBmb6	Sandy loam; sl darker than 120-128; calc w sec lime fil;
135-360	VIIIBm2b6	Sandy loam gradationally fining downwards; weak horizontal partings; eolian-cumulic soil profile;
360-363	IXAhb7	Silt loam; 2.5Y 4/2; calc;
363-480+	IXBmb7	Silt loam; 2.5Y 4/4; calc; wet and soft; perched water, probably on lacustrine clay just below 480 cm.

Stratigraphic observations at station K4.3, Kipp area.

Depth	Horizon	Description
000-003	Ah	Sandy loam; calc;
003-009	IIAhb1	Sandy loam; calc;
009-021	IIBmb1	Sandy loam; calc;
021-022	IIIC	Fine sand; calc;
022-027	IVBmb2	Sandy loam; calc;
027-030	VC	Fine sand; calc;
030-038	VIB/Cb3	Sandy loam; calc;
038-042	VIIC	Fine sand; calc;
042-059	VIIIbmb4	Sandy loam; calc;
059-065	IXC	Fine sand; calc;
065-067	XAhb5	Sandy loam; calc;
067-073	XIC	Fine sand; calc;
073-080	XIIAhb6	Sandy loam; calc;
080-086	XIIIC	Fine sand; calc;
086-094	XIVAhb7	Sandy loam; dk grayish brn; calc;
094-116	XIVBmb7	Sandy loam; mod to strong fine prismatic; wk colloid coatings on vertical cleavages; calc;
116-135	XVAh/Bmb8	Sandy loam; dk gr brn; mod fine prismatic; dark staining in upper 5 cm; calc;
135-142	XVIAh/Bmb9	Same as 116-135, marked by dark stained zone;
142-155	XVIIAhb10	Sandy loam; mod fi sb bk; dark ct on peds; calc;
155-260	XVIIIBmb11	Sandy loam, gradationally fining (less gritty) downwards; wk fi prismatic; wk colloid ct on vertical cleavages; calc;
260-268	XIXC	Silt loam; volcanic ash bed (confirmed); calc;
268-385	XXBmb12	Sandy loam, gradationally fining downwards; olive brn; wk fi sb bk; calc; "giant" Bmb;
385-390	XXIAhb13	Silt loam; dk gr brn; massive; wet; calc;
390-470	XXIIBmb13/C	Silty clay loam; soft and wet; calc; "ash-like" sample taken from 430 cm;
470-480+	XXIIIC	Clay loam; olive brn; dense; calc; top of caly-and-silt rhythmites.

Stratigraphic observations at station K4.4, Kipp area.

Depth	Horizon	Description
000-003	Ah	Loamy sand (lsa) to sandy loam (sal); calc;
003-008	IIAhb1	Lsa to sal; calc;
008-016	IIBmb1	Lsa to sal; calc;
016-028	IIIC	Fine sand; calc;
028-046	IVBmb2	Lsa to sal; calc;
046-055	VC	Fine sand; calc;
055-070	VIBmb3	Lsa to sal; calc;
070-076	VIIC	Fine sand; calc;
076-103	VIIIIBmb4/C	Lsa to sal; calc;
103-107	IXC	Fine sand; calc;
107-119	XBmb5	Sal; calc;
119-125	XIAhb6	Sal; dk gr brn; calc;
125-156	XIBmb6	Sal; mod fi prismatic w mod fi sb bk; locally platy partings; colloid coatings on vertical cleavages; calc w sec lime fil on roots and on horizontal partings;
156-280	XIIBmb7	Sal; similar to above but w stronger pedality;
280-305	XIIIAhb8	Sal fining downwards towards silt loam; dk gr brn; calc; w common fi sec lime fil and specks;
305-339	XIIIBmb8	Lightly sandy silt loam; calc;
339-360	XIVBg1b9	Silt loam; few fi dist grayish mottles; calc;
360-370	XIVBg2b9	Silt loam; same as above but coarser mottles;
370-390	XVBC	Clay; slightly altered top of glaciolacustrine sequence; calc;
390-480	XVC	Silt-and-clay rhythmites; calc w sec gypsum in pockets.

Stratigraphic observations at station K4.5, Kipp area.

Depth	Horizon	Description
000-003	Ah	Sandy loam (sal) to loamy sand (lsa); massive; calc;
003-010	IIAhb1	Sal to lsa; calc;
010-065	IIB/Cb1	Sal to ls; calc;
065-100	IIIC	Fine sand (fi sa); loose; calc;
100-122	IVBmb2	Sal; firm; calc w sec lime fil;
122-124	VAhb3	Sal; calc;
124-128	VBmb3	Sal; calc;
128-140	VIAhb4	Sal; dark olive brn; calc;
140-172	VIBmb4	Sal; str fi sb bk; calc w sec lime fil;
172-174	VIIAhb5	Sal; calc;
174-193	VIIBmb5	Sal; calc;
193-230	VIIIBmb6	Sal fining downwards to silt loam; calc;
230-260	IXBmb7	Silt loam; calc;
260-285	IXC	Silt loam; calc;
285-300	XAh/Bmb8	2.5Y 4/4 (dk ol brn); silt loam; wk fi sb bk; wk coatings on peds; distinct fi biopores; calc;
300-330	XIBmb8	Clay loam w dropstone; calc; pedogenically altered top part of glaciolacustrine sequence;
330-480+	XIC	Clay- and silt rhythmities; glaciolacustrine sequence.

Stratigraphic observations at station K4.6, Kipp area.

Depth	Horizon	Description
000-003	Ah	2.5Y 4/4; sandy loam (sal); very weak fine crumb; calcareous (calc); abrupt boundary (abr bd);
003-008	IIAhb	2.5Y 4/2; sl; weak (wk) fine (fi) subangular blocky (sb bk) to granular; calc; abr bd;
008-018	IIBmb	2.5Y 4/4; sl; wk fi sb bk; calc; abr bd;
018-020	IIIC	2.5Y 5/4; sand; single grain; calc; abr bd;
020-042	IVBmb	2.5Y 5/2; sl; wk fi sb bk; calc; abr bd;
042-046	VC	2.5Y 5/4; sand; single grain; calc; abr bd;
046-088	VIBmb	2.5Y 5/3; sl; wk fi sb bk; calc; abr bd;
088-099	VII Bmb	2.5Y 5/3 (upper 2 cm include pocket of 2.5Y 4/2); sl; wk fi sb bk; abr bd;
099-158	VIII Bmb	2.5Y 4/3; sl; wk fi sb bk with faint prismatic overprint; calc w secondary (sec) lime filaments (fil); abr bd;
158-177	IX Bmb	2.5Y 4/3; sl; wk fi sb bk with faint platiness; calc w sec lime fil; abr bd;
177-185	XC	2.5Y 5/4; fi sa; single grain; calc; abr bd;
185-196	XI Bmb	2.5Y 4/3; sl; very wk fi sb bk; wk platiness; calc w sec lime fil; abr bd;
196-260	XII Bmb	2.5Y 4/4; sl; moderate fi sb bk with mod fi prismatic; weak colloid coatings on prisms; calc; abr bd;
260-268	XIII Bm1b	2.5Y 6/4; silt loam; mod fi sb bk; burrow channels (1 mm) filled with material similar to XII Bmb; calc; abr bd;
268-284	XIII Bm2b	2.5Y 5/4; gritty sandy clay loam; wk to mod fi sb bk; calc; abr bd;
284-300	XIV Bm3b	2.5Y 4/4; clay loam; mod med sb bk and weakly platy; calc w sec lime in small (<2 mm) nodules; abr bd;
300-360	XIV C	2.5Y 4/4; clay (glaciolacustrine); massive; calc w sec lime and gypsum fil and pockets.

---Cored in swale and described by W.J. Vreeken, August 5, 1989.

Table K4.7 Stratigraphic Observations at Kipp, Station 4.7

Depth	Horizon	Description
000-006	Ah	10YR 4/2 (dk gr brn); fine sandy loam (fi sal); very fine (v fi) granular; upper 2 cm noncalcareous, rest calcareous (calc); abrupt boundary (abr bd);
006-019	Bm	2.5Y 5/3; fi sal; v wk co sb bk to massive; calc; abr bd;
019-022	IIAhb1/Bmb1	2.5Y 4/4; fi sal; v wk v fi sb bk to massive; calc; abr bd;
022-028	IIBm2b1	2.5Y 5/2; fi sal; v wk v fi sb bk to massive; calc; abr bd;
028-038	IIIAhb2	2.5Y 4/2; v fi sal; wk fi sb bk; calc; abr bd;
038-069	IIIBmb2	2.5Y 5/3; sal (sandier than above and below); wk med sb bk to single grain; calc; abr bd;
069-105	IVBmb3	2.5Y 4/4; sal; mod fi prismatic w mod co sb bk; slightly stained ped coatings; calc w few but continuous sec lime filaments (fil); abr bd;
105-123	VBmb4	2.5Y 4/4; mod fi sb bk and, near base, mod fi platy; otherwise as above; abr bd;
123-133	VIAhb5	2.5Y 4/2; fi sal; wk fi sb bk w wk fi prismatic; calc w sec lime fil; abr bd;
133-154	VIBmb5	2.5Y 4/4; fi sal; wk fi sb bk w v wk fi prismatic; calc; abr bd;
154-164	VIIAhb6	2.5Y 4/2 w black (N2) flecks and charcoal specks; fi sal; wk fi sb bk; calc; burned horizon; abr bd;
164-215	VIIIBmb6	2.5Y 5/4; wk fi prismatic w wk fi sb bk in upper 30 cm, grading to massive at depth; calc; abr bd;
215-298	VIIIIBmb7	2.5Y 4/4; fi sal; mod fi sb bk w wk fi prismatic; calc w sec lime fil; "giant" Bm; abr bd;
298-355	IXBmb8	2.5Y 4/4; same as above, but distinguished by slightly stronger sb bk structure; abr bd;
355-375	XAh/Bmb9	2.5Y 4/3; v fi sal; wk fi sb bk; calc w v few sec lime fil; abr bd;
375-387	XIAh/ Bmb10	2.5Y 4/4; fi sal; v wk fi sb bk to massive; calc w v few sec lime fil; abr bd;
387-397	XIIAhb11	2.5Y 3/2; silt loam; wk fi sb bk; biotubules (1 cm thick); calc; clear bd;
397-426	XIIBmb11	2.5Y 5/4; silt loam; wk fi sb bk w wk fi platy; calc; abr bd;
426-480+	XIIIC	2.5Y 4/4; silt-and-clay rhythmites; mod to str pseudo sb bk; calc w sec gypsum pockets; glaciolacustrine rhythmites.

Table k4.8. Stratigraphical Observations on AgCan Site, near Kipp, Alberta. Drill Core #K4.8 - along gravel road and fence around Radio Tower lot, "in the corner" of the field at the beginning of the N - S transect.

Depth (cm)	Unit	Observations
- 4	IAh 10	YR 5/3 (brown); sandy loam; moderate medium crumb; frequent roots; noncalcareous; abrupt boundary.
4 - 33	Bm	10 YR 5/4 (yellowish brown); sandy loam; moderate medium prismatic; common roots; calcareous; abrupt boundary.
33 - 34	IIBm1 b1	10 YR 4/2 (dark greyish brown); sandy loam; moderate medium prismatic; calcareous; few roots; abrupt boundary.
		Note: This is tentatively interpreted to be the truncated top of a paleosol, on the basis of its colour.
34 - 68	Bm2b1	10 YR 5/4 (yellowish brown); sandy loam; moderate medium prismatic; calcareous; few roots; abrupt boundary.
68 - 71	IIIAhb2	10 YR 3/2 (very dark greyish brown); sandy loam; massive; very few roots; calcareous; abrupt boundary.
71 - 93	Bmb2	10 YR 5/4 (yellow brown); sandy loam; moderate medium prismatic; very few roots; calcareous; abrupt boundary.
93 - 97	IVAhb3	10 YR 4/2 (dark greyish brown); sandy loam; massive; calcareous; very few roots; abrupt boundary.
97 - 118	Bmb3	10 YR 5/3 (brown); sandy loam; moderate coarse subangular blocky; very few roots; calcareous; distinct, white, thin secondary carbonate accumulations on vertical and horizontal cleavages; abrupt boundary.
118 - 121	VAhb4	10 YR 4/2 (dark greyish brown); sandy loam; massive; calcareous; very, very few roots; very faint secondary carbonates, as above; abrupt boundary.
121 - 185	Bmb4	10 YR 5/4 (yellowish brown); sandy loam; moderate medium prismatic; calcareous; abrupt boundary.
185 - 203	VCCab4	10 YR 5/4 (yellowish brown); sandy loam; moderate medium prismatic; calcareous; pronounced secondary carbonates till 203cm, secondary carbonates soft, white, thin accumulations mostly in prismatic cleavages; abrupt boundary.
		Note: 185 cm is arbitrarily taken as B-C boundary.
203 - 340	VC	same as above, but less secondary carbonates
340 - 480+	VIC	10 YR 3/2 clay alternating with 10 YR 7/2 silt; lacustrine sequence - beds; calcareous.

Note: The entire core is bone dry.

Summary: 0 - 340cm loess with paleosol
340 - 480+ cm lacustrine sequence

Table K4.9... Stratigraphical Observations at Kipp, Station K4.9.

Depth	Horizon	Description
000-006	Ah	2.5Y 4/2; sal;
006-010	Bm	2.5Y 4/4; sal;
010-020	IIAhb1	2.5Y 4/2; sal;
020-035	IIBmb1	2.5Y 5/4; sal;
035-054	IIIAhb2	2.5Y 3/2; sal;
054-082	IIIBmb2	2.5Y 4/4; sal;
082-090	IVAhb3	2.5Y 3/2; sal;
090-115	IVBmb3	2.5Y 5/4; fi sal fining downwards;
115-123	VBm2b3	2.5Y 4/4; fine sal to sil; colloid ct (2.5Y 4/2) on vert planes;
123-133	VI Ahb4	2.5Y 4/2; sil;
133-169	VIBmb4	2.5Y 4/4; sil;
169-180	VII Ahb5	2.5Y 3/2; sil;
180-236	VII Bmb5	2.5Y 4/4; sil; wk fi platy (lam) to massive; soft;
236-360	VIII C	Clay (2.5Y 3/2) and silt (2.5Y 4/4 to 5/4) rhythmites; glaciolacustrine.

Table K4.10. Stratigraphical Observations on AgCan Site, near Kipp, Alberta. Drill Core #K4.10 - located between K4.8 and K4.14 about 1/2 way, along the N-S transect.

Depth	Horizon	Observations
000-008	IAh	10 YR 5/3; sl; mod med prism; 000-003 uncalc, 003-008 calc; abr bd; <u>Note:</u> Ah modified by road traffic.
008-028	Bm	10 YR 5/4; sl; mod fi prism; calc; dk coatings on peds; abr bd;
028-037	IIAhb1	10 YR 4/3; sl; mod med sb bk; calc; abr bd;
037-075	Bm1b1	10 YR 5/4; sl; mod med sb bk; calc; slight staining on the peds; abr bd;
075-165	Bm2b1	10 YR 5/4; sl; mod med sb lk in mod med prism; calc w sec carb in dist veins; abr bd;
165-210	Bm3b1	10 YR 5/4; sl; mod fi prism; calc; abr bd;
210-233	IIIAhb2	10 YR 4/3; sil; mod med prism; calc; dist sl infillings in faunal burrowings (specimen saved - L84); sec carb in veins; abr bd;
233-280	Bm1b2	10 YR 6/3; sil; mod med prism; calc; slight staining on peds; abr bd;
280-310	Bm2cab2	10 YR 5/4; sil; mod med prism; calc w sec carb in veins; slight staining on peds; abr bd; <u>Note:</u> The boundary at 280cm might be a lithological boundary. Must be checked analytically.
310-345	IVC	Lacustrine sequence w si and clay as described before.

Summary:

0 - 28	loess I
28 - 210	loess II
210 - 310	loess III - may be IIIa (210-280) and IIIb (280-310)
310 - 345+	lacustrine IV

Table K4.11... . Stratigraphical Observations at Kipp, Station 4.11

Depth	Horizon	Description
000-005	Ah	Sandy loam; calc;
005-013	Bm	Sandy loam; calc;
013-027	IIAhb1	Sandy loam; calc;
027-037	IIBmb1	Sandy loam; calc;
037-057	IIIAhb2	Sandy loam; calc;
057-170	IIIBmb2	Sandy loam; "giant" eolian-cumulic B; calc;
170-177	IVC	Silt; tephra bed; calc;
177-183	VC	Sandy loam; calc;
183-189	VIC	Silt;tephra bed; calc;
189-202	VIIIBmb3C	Sandy loam fining down; "giant" cumulic B; calc;
202-270	VIIIBmb4C	2.5Y 4/4; silt loam; calc w sec gypsum myc; cumulic B;
270-308	IXAhb5	2.5Y 4/4; silt loam; wkly laminated w 2.5Y 4/2 ct; calc; aeolian/colluvial-cumulic A;
308-362	XABb5	2.5Y 4/4; silt loam; calc; eolian-colluvial-cumulic;
362-465	XI	Clay-and-silt rhythmites; upper 30 cm well-turbated w fine (2-3 mm) clay balls; clear rhythmites below 380 cm; glaciolacustrine.

Table K4.12. Stratigraphical Observations on AgCan Site, near Kipp, Alberta. Drill Core #K4.12 - in field between swale and crest (K4.8), along N - S transect.

Depth	Horizon	Observations
000-012	IAh	10 YR 4/3; sl; mod med sb bk; noncalc; abr bd;
012-025	Bm	10 YR 5/3; sl; mod fi sb bk; calc; abr bd;
025-040	IIAhb1	10 YR 4/2; sl; mod fi sb bk; calc; abr bd;
040-055	Bm1b1	10 YR 4/3; sl; mod med prism; calc; slight dk staining on peds; abr bd;
055-110	Bm2b1	10 YR 5/3; sl; mod med prism; calc; slight dk staining on peds; ft sec carb; abr bd;
110-205	Bm3b1	10 YR 5/4; sil; mod co prism; calc w dist accum sec carb in fi soft nod (2mm), in patches; abr bd; <u>Note:</u> Possibly there is a lithological discontinuity at 110 cm; if so 110-205 will be called IIIBmb2.
205-245	IIIBmb2	10 YR 5/4; sil (fi texture than 110-205); mod co sb bk; calc; dk staining on peds; v ft colour separations; f powdery gypsum accum; abr bd; <u>Note:</u> 240-245 has f scattered accum of pure clay (v dk grey), 2-3 mm.
245-265	IVBmb2	10 YR 3/1 clay and 10 YR 4/3 si; wk to mod med sb bk; calc; powdery gypsum in veins and small pockets.

Note: Core blocked at 2.85 m by heavy clay.

Summary:

0 - 40	loess - sandy
40 - 110	loess - sandy) may be one
110 - 205	loess - silty) unit
205 - 245	loess - silty
245 - 265+	lacustrine clays

Table k4.13. Stratigraphical Observations on AgCan Site, near Kipp, Alberta. Backhoe trench (K4.13)- located between K3. and K3.14. Trench measured 9 m long, 2.5 m wide, and 4 m at it deepest point. The west side was benched to 1.5 m for safety and the length was graded towards the north to allow for easy access. The trench ran N-S along the drill transect.

Depth	Horizon	Observations
000-013	IAh	10 YR 4/2; sl; mod med crumb; noncalc; abr bd;
013-018	Bm	10 YR 4/3; sl; mod med sb bk; calc; abr bd;
018-028	IIAhb1	10 YR 3/3; sl; mod fi sb bk; calc; abr bd;
028-043	Bmb1	10 YR 4/3; sl; mod med sb bk; calc; abr bd;
043-056	IIIAhb2	10 YR 4/2; sl; mod med prism; calc; abr bd;
056-081	Bmb2	10 YR 4/3; sl; mod med prism; calc; abr bd;
081-183	IVBmb3	10 YR 4/3; sil; mod med prism; calc w sec carb in veins; slight dk staining on peds; abr bd;
183-191	VAhb4	10 YR 4/3; sil; mod fi sb bk; calc; abr bd;
191-231	Bmb4	10 YR 4/4; sil; mod med sb bk; calc w f diffuse sec carb in veins; slight dk staining on peds; abr bd;
231-243	Bmb5	10 YR 3/4; sil; mod med sb bk; calc; abr bd;
243-269	VIBmb6	10 YR 5/3; si clay loam; mass; calc; abr bd;
269-300	VIIC	10 YR 5/3; si clay loam; mass; calc; abr bd;
300-323	VIIIC	10 YR 4/3; si clay loam; mass; calc; some clay nod visible; abr bd;
323-366	IXC	10 YR 3/2; si clay loam; mass; calc; clay nod visible; abr bd;

Note: The boundary between loess and lacustrine clays taken at 323 cm.

Summary:

- 0 - 191 loess I
- 191 - 243 loess II
- 243 - 323 loess III (transitional ?)
- 323 - 366 lacustrine clays

Note: No stones/pebbles or shells were noted in the entire trench.

Table K4.14. Stratigraphical Observations on AgCan Site, near Kipp Alberta. Drill Core #K4.14 - in field between K4.13 and K4.15 along N-S transect.

Depth (cm)	Unit	Observations
- 15	IAh	10 YR 4/3 (brown to dark brown); sandy loam; moderate medium subangular blocky, noncalcareous; frequent roots, abrupt boundary.
15 - 33	Bm	10 YR 5/4 (yellowish brown); sandy loam; moderate fine subangular blocky; calcareous; common roots; abrupt boundary.
33 - 45	IIAhb	10 YR 4/2 (dark greyish brown); sandy loam; moderate medium crumb; few roots; calcareous, abrupt boundary.
45 - 117	Bmb1	10 YR 5/4 (yellowish brown); sandy loam; moderate medium subangular blocky; very few roots; calcareous; abrupt boundary.
117 - 225	IIIBm2b2	10 YR 5/4 (yellowish brown); silty loam; moderate medium prismatic; calcareous with distinct secondary carbonates in patches and veins (2mm fine soft nodules); slight dark staining on the peds; abrupt boundary. <u>Note:</u> Possibly corresponds to lithologic discontinuity of Ag7 at 110-117cm (Bm2b1).
225 - 242	IVAhb3	10 YR 3/3 (dark brown); silty loam; moderate medium prismatic; calcareous, abrupt boundary.
242 - 252	VAhb4	10 YR 3/2 (very dark greyish brown); silty clay loam; massive; calcareous; abrupt boundary. <u>Note:</u> Buried mucky A horizon.
252 - 265	Bmb4	10 YR 4/2 (dark greyish brown); silty clay loam; massive, calcareous; burrowing feature (channels) mark the contact at 252cm and at 265cm, abrupt boundary.
265 - 275	VIAhb5	10 YR 3/2 (very dark greyish brown); silty clay loam; massive; calcareous; abrupt boundary.
275 - 412	Bmb5	10 YR 3/3 (dark brown); silty clay loam; weak medium to coarse prismatic; calcareous; slight darker coatings on peds; at 320cm change from lower (above) to higher density: lower part is stiff; at 295cm, thin (1/2 cm) darker band; abrupt boundary.
412 - 465	VIIC	10 YR 4/2 (dark greyish brown) silt dominates with 10 YR 3/1 (very dark grey) clay bands; essentially massive; top of lacustrine unit taken at top of uppermost distinct clay band.

Table K4.15. Stratigraphical Observations on AgCon Site, near Flipp, Alberta. Drill Core #K4.15 - located between K4.14 and K4.16, along N-S trend.

Depth (cm)	Unit	Observations
- 5	IAh	10 YR 4/3 (dull yellowish brown); sandy loam; moderate medium crumb; frequent roots; noncalcareous; abrupt boundary.
5 - 13	Ba	10 YR 5/3 (dull yellowish brown); sandy loam; moderate fine subangular blocky; common roots; noncalcareous; abrupt boundary.
13 - 19	IIAh	10 YR 4/2 (greyish yellow brown); sandy loam; moderate fine subangular blocky; few roots; noncalcareous; abrupt boundary.
19 - 46	Bm1b1	10 YR 5/3 (dull yellowish brown); sandy loam; moderate medium subangular blocky; very few roots; calcareous; slight dark staining on the peds; abrupt boundary.
46 - 50	IIIAhb2	10 YR 4/2 (greyish yellow brown); sandy loam; moderate medium subangular blocky; very few roots; calcareous; abrupt boundary.
50 - 64	Bm1b2	10 YR 5/2 (greyish yellow brown); sandy loam; moderate medium prismatic; very few roots; calcareous; slight dark staining on the peds; abrupt boundary.
64 - 122	Bm2b2	10 YR 6/3 (dull yellow orange); sandy loam; moderate medium subangular blocky; very few roots; calcareous with few secondary carbonates in veins; slight dark staining on the peds; abrupt boundary.
122 - 208	Bm3b2	10 YR 6/3 (dull yellow orange); sandy loam; moderate medium prismatic; calcareous with abundant secondary carbonates in veins; slight dark staining on the peds; abrupt boundary. Note: This layer shows signs of compaction during drilling, along the edge. Note: 64-208cm may be the same layer, but there is a difference in the amount of secondary carbonate present in each layer.
208 - 241	Bm4b2	10 YR 6/2 (greyish yellow brown); sandy loam; moderate medium subangular blocky; calcareous; very few secondary carbonates in veins; slight dark staining on the peds; abrupt boundary. Note: This layer shows little or no secondary carbonate compared with the previous two layers.
241 - 252	IVAhb3	10 YR 5/2 (greyish yellow brown); sandy loam; moderate medium prismatic; calcareous; abrupt boundary.
252 - 340	Ba1b3	10 YR 7/2 (dull yellow orange); sandy loam; moderate medium prismatic; calcareous with few secondary carbonates in veins; slight dark staining on the peds; abrupt boundary.
340 - 366	VAhb4	10 YR 6/2 (greyish yellow brown); silty clay loam; moderate medium subangular blocky; calcareous with some secondary carbonates in veins; abrupt boundary.
366 - 396	VIAhb5	10 YR 3/2 (brownish black); silty clay loam; moderate medium subangular blocky; calcareous; some clay nodules; abrupt boundary.
396 - 399	VIIAhb6	2.5 Y 8 1 (light grey); silt (ash?); moderate fine crumb; calcareous; abrupt boundary. Note: Initial microscopic observations indicate that this could indeed be an ash, possibly useful in dating this sequence. Further observations are to be gathered using microprobe.
399 - 455	VIIIDm1b5	10 YR 4/2 (dark greyish yellow); silty clay loam; massive; calcareous; abrupt boundary.
455 - 478	IXC	0 YR 4/2 (dark greyish yellow) clay (1-2cm) bedded with 10 YR 6/2 (greyish yellow) silt (3-4cm); calcareous; abrupt boundary.

Table k4.16. Stratigraphical Observations on AgCan Site, near Kipp, Alberta. Drill Core #K4.16 - in first swale - S. of communication tower along N-S transect.

Depth (cm)	Unit	Observations
- 15	IAh 10	YR 4/3 (brown to dark brown); sandy loam; compound pseudoplaty with angular blocky structure (10-20 mm), medium; noncalcareous; common to many roots; abrupt boundary (bd).
15 - 25	Bm	10 YR 3/3 (dark brown); sandy loam; weakly pseudoplaty, weakly prismatic and weakly subangular blocky, coarse; calcareous; few to common roots; abrupt boundary.
25 - 35	IIAhb 1	10 YR 4/3 (brown to dark brown); sandy loam; weakly pseudoplaty, weak fine subangular blocky, very weakly prismatic, medium to coarse; calcareous; few roots; abrupt boundary.
35 - 80	Bmb 1	10 YR 5/3 (brown); sandy loam; very weakly pseudoplaty, medium moderate prismatic; calcareous; very few roots; relatively dark stains or coatings on the prismatic peds; abrupt boundary.
80 - 150	IIIBmb 2	10 YR 5/3 (brown); sandy loam; coarse prismatic to more massive; calcareous; very few if any roots; dark staining or coating on the prismatic peds; abrupt boundary.
150 - 190	IIIC	10 YR 5/3 (brown); sandy loam; coarse prismatic, calcareous; no roots; darker stains or coatings on prismatic peds; diffuse boundary.
190 - 250	IVC	2.5 Y 4/2 (dark grayish brown) silt with 2.5 Y 3/2 (very dark greyish brown) clay balls; clay is concentrated and rounded (3 mm - 1 cm); clay and silt; clay balls or separation in a silt matrix; at 25 cm depth below top of clay-silt horizon is a clay layer 3 cm in thickness, very dark greyish brown; pseudostructure - nonpedogenic; calcareous (clay and silt matrix); veins of gypsum are also visible, white, sugar-like crystals in

Table K4.17 . Stratigraphical Observations at Kipp, Station 4.17

Depth	Horizon	Description
000-003	Ah	2.5Y 5/4; sal; v wk fi gran to single grain; noncalc; recent dust; abr bd;
003-015	IIAh1b1	2.5Y 3/2; sal; wk fi platy @ mod fi sb bk; noncalc; abr bd;
015-020	IIAh2b1	Same as above but calcareous; abr bd;
020-071	IIBmb1	2.5Y 4/4; sal; mod to str fi prism @ str fi sb bk; wk colloid ct on vertical planes; calc; abr bd;
071-084	IIIBmb2	2.5Y 4/4; sal to sacl; mod to str fi prism @ str fi to med sb bk; mod to str ct (2.5Y4/2) ct on vert planes; calc; abr bd;
084-117	IVBmb3	2.5Y4/2 clay w turbated incl of 2.5Y 4/4 silt; mod fi sb bk @ mod fi prism; calc w sec gypsum myc on prism faces; abr bd;
117-120	IVC	Clay-and-silt rythmites; colors as in 084-117 cm; massive; calc w sec gypsum; glacio-acustrine.

Table K4.18. . Stratigraphical Observations at Kipp, Station 4.18.

Depth	Horizon	Description
000-050	Bm	2.5Y 4/4; sal; str fi @ med sb bk; calc; no A horizon; abr bd;
050-077	IIBmb1	2.5Y 4/2 clay and 2.5Y 4/4 silt rhythmites; mod to str med sb bk; original beds pedoturbated; calc; abr bd;
077-120+	IIC	Distinct inclined rhythmites; glaciolacustrine.

Table k4.19. Stratigraphical Observations on AgCan Site, near Kipp, Alberta. Drill Core #4.19 - on small ridge - S. of communication tower, along N-S transect in southern most corner of field, approx. 15m from gate, at bend in the road.

Depth (cm)	Unit	Observations
- 14	IAh	10 YR 4/4 (dark yellowish brown); sandy loam; moderate medium crumb; many roots; 0-4 cm noncalcareous, calcareous; abrupt boundary.
14 - 40	Bm	10 YR 4/3 (brown to dark brown); sandy loam; moderate medium subangular blocky; many roots; calcareous; thin coatings, dark stained peds; one round pebble (1 cm); abrupt boundary.
40 -65	IIBmb	10 YR 3/3 (dark brown); clay loam; moderate medium prismatic; few roots; calcareous; dark stained coatings on peds, dense peds; abrupt boundary.
65 - 80	Bm b 2	10 YR 3/3 (dark brown); clay loam; moderate coarse prismatic; calcareous; very few roots; dark stained peds; inclined shear planes (20° - 30°) denoting relict sedimentary bedding; abrupt boundary.
80 -120	IIBCb	10 YR 7/2 (light grey) silt beds (3-4cm) alternating with 10 YR 3/1 (very dark grey) clay beds (1-2 cm); moderate coarse to very coarse prismatic; calcareous; very few roots along vertical cleavages; inclined (20°-30°) beds marked by slickensided shear planes; deformed glaciolacustrine rhythmites.

Summary : 0 - 40cm loess

40 - 120cm glaciolacustrine clays

Table k4.20. Stratigraphical Observations on AgCan Site, near Kipp, Alberta. Drill Core #4.20 - in middle of road on crest of low ridge, due south of bend in road, almost due east of strawstack, along N-S transect.

Depth (cm)	Unit	Observations
- 12	IAh	10 YR 4/2 (dark greyish brown); sandy loam; moderate medium crumb to moderate fine subangular blocky; noncalcareous; many roots; abrupt boundary.
12 - 17	Bm 1	10 YR 4/3 (brown to dark brown); sandy loam; moderate medium subangular blocky; noncalcareous; frequent roots; abrupt boundary.
17 - 42	Bm 2	10 YR 4/3 (dark brown); sandy loam; moderate coarse subangular blocky and moderate medium prismatic; frequent roots; calcareous; dark stained coatings on vertical cleavages; abrupt boundary.
42 - 70	Bm ca 3	10 YR 6/3 (pale brown); sandy loam; moderate medium to coarse prismatic; calcareous with secondary carbonates; common roots in diffuse concentrations; abrupt boundary.
70 - 87	IIBmb (?)	10 YR 6/3 (pale brown) silt (3-4cm) interbedded with 10 YR 4/2 (dark greyish brown) clay (1-2cm); moderate fine subangular blocky; few roots; calcareous; thin discontinuous dark stained coatings on peds; clear boundary.
87 - 240+	IIC	Complex dominated by pale brown silt loam with few thin (<1cm) dark greyish brown to black clay interbeds and locally, pale brown thin (approx. 20cm) diamictic (clay loam) interbeds. Fine crystalline gypsum in pockets and on bedding planes. Glaciolacustrine complex.

Note: Loess thickness on this crest is unexpectedly low. Possibly greater loess thickness is represented E-NE from this site (see drill core #5).

Also, south of St. K3.20 is a well-defined thalweg in side valley angularly cut below the adjacent interfluves. (Cannot be crossed with the drill). Lacustrine clays are exposed in the bottom. To the west of the N-S road, the terrain probably marks the lake bed (Glacial Lake McLeod) and likely has no significant wind deposits at all. The loess is thickest on the ridge marked by the communication tower.

Summary: I 0 - 70cm loess
II 70 - 240+ glaciolacustrine rhythmites with thin diamicton-like interfluves.

Table k5.1. Stratigraphical Observations on AgCan Site, near Kipp, Alberta. Drill Core #K5.1 - corner of field along road

Depth (cm)	Unit	Observations
-11	IAh 10	YR 4/2 (dark greyish brown); sandy loam; moderate fine to medium subangular blocky; noncalcareous; many roots; abrupt boundary.
11 - 28	Bm1(Bhm1)10	YR 3/3 (dark brown); sandy loam; moderate medium subangular blocky; common roots; noncalcareous; abrupt boundary.
28 - 65	Bm2	10 YR 6/3 (pale brown) with 10 YR 5/4 (yellowish brown) coatings on vertical cleavages; sandy loam; moderate medium prismatic; few roots; calcareous; clear boundary.
65 - 95	Bm3	10 YR 6/3 (pale brown) silt loam (gradational to sandy loam, loam in overlying horizon); moderate medium prismatic; faint coatings on peds; calcareous; very few roots; diffuse or faint accumulations of secondary carbonates; abrupt boundary.
95 - 108	IIBm4	10 YR 6/3 (pale brown); silty clay loam; moderate medium prismatic; calcareous with few secondary carbonates; very few roots; abrupt boundary.
108 - 120+	IIIC	10 YR 5/2 (greyish brown) silt (3cm) with 10 YR 3/1 (very dark grey) clays (1.5cm); rhythmites clearly bedded; calcareous; very few roots.

Question Why is there so little loess?

Summary: 0-108 cm loess
108-120+ cm glaciolacustrine rhythmites

APPENDIX B

Analytical data
K4.6, K4.8, K4.10, K4.12, K4.15

Analytical Data for Kipp, Station K4.6

Depth cm	Change in depth product	*Cross Horizon	Hurst (V(4C))	Colour	pH	OC %	Carb %	2M %	4- 2p	8- 4p	16- 8p	31- 16p	62- 31p	2000 62p	125p 125p	250- 500p	500- 1000p	1000- 2000p	Silt + Clay	
0-3	3	3.24 Ah	144	2.5Y 4/4	6.7	1.08	8.17	10.2	2.78	1.62	1.85	4.17	17.39	61.99	19.19	16.25	24.4	1.35	0.8	38.01
3-8	5	5.25 IIAhb	72	2.5Y 4/2	7.3	1.05	5.92	10.3	2.09	2.09	2.55	4.17	10.6	28.3	17.05	22.71	25.6	2.53	0.41	28.92
8-18	10	7.9 Bmb	144	2.5Y 4/4	7.6	0.79	6.93	10.43	2.09	2.09	1.16	2.78	10.37	71.08	11.62	21.1	12.44	3.41	0.51	16.04
18-20	2	1.16 IIC	180	2.5Y 5/4	7.7	0.58	4.93	5.33	0.93	0.3	4.8	0.93	5.37	81.96	9.39	25.01	44.29	4.79	0.48	16.04
20-31	11	7.37 IVBmb	90	2.5Y 5/2	7.8	0.67	6.08	9.5	1.85	1.62	2.09	4.4	14.05	66.49	23.19	27.86	12.67	0.65	0.12	33.51
31-42	9	5.85 Bmb	90	2.5Y 5/4	7.9	0.65	6.5	15.06	1.85	2.55	2.09	3.71	10.45	64.29	17.13	28.09	18.09	0.79	0.19	35.71
42-46	4	2.56 VC	180	2.5Y 5/4	7.9	0.64	6.5	10.2	2.32	1.62	2.09	4.87	10.37	68.53	23.17	27.12	17.33	0.88	0.03	31.47
46-60	14	10.22 VIBmb	135	2.5Y 5/3	7.9	0.73	5.75	13.9	2.55	4.17	2.09	3.94	7.76	55.59	26.97	28.53	9.47	0.48	0.14	34.41
60-74	14	9.1 Bmb	8	0.85	8.83	19.46	3.48	3.24	3.01	3.71	12.14	54.96	24.72	24	5.64	0.3	0.3	0.3	0.3	45.04
74-88	10	6.6 Bmb	135	7.9	0.56	6.92	22.48	4.87	2.78	2.78	3.24	10.94	52.91	29.17	20.36	2.74	0.38	0.26	0.26	47.09
88-99	11	6.71 VIIIBmb	135	2.5Y 5/3	7.9	0.61	8.67	25.72	3.94	3.24	3.01	3.71	12.79	47.59	25.96	18.54	2.91	0.22	0.06	52.41
99-110	15	11.4 VIIIBmb	108	2.5Y 4/3	8	0.76	9	14.99	8.11	5.1	3.94	2.78	11.16	33.92	16.85	14.37	2.08	0.37	0.25	66.08
110-125	15	10.95 Bmb	108	2.5Y 4/3	8	0.73	11.5	43.33	8.81	5.66	3.94	3.01	14.08	21.27	11.69	7.98	1.29	0.23	0.08	78.73
125-140	15	9.45 Bmb	108	2.5Y 4/3	8	0.57	10.2	39.62	8.71	6.49	2.32	2.78	17.06	24.32	14.64	8.23	1.2	0.14	0.11	75.48
140-158	18	10.26 Bmb	108	2.5Y 4/3	8	0.46	10.1	32.44	5.56	5.1	3.71	4.17	17.48	31.54	21.96	8.25	1.15	0.12	0.06	68.46
158-167	9	4.14 IXBmb	108	2.5Y 4/3	8.1	0.43	8.17	20.62	3.71	3.71	2.32	5.1	16.32	48.22	33.32	13.72	1.02	0.1	0.01	38.09
167-177	10	4.3 Bmb	180	2.5Y 5/4	8.3	0.29	7	11.12	2.78	1.85	1.16	5.1	16.08	61.91	38.58	20.21	2.97	0.18	0.01	38.09
177-185	8	2.32 XC	108	2.5Y 4/3	8.15	0.46	8.58	27.9	5.1	4.17	1.24	3.94	15.55	40.2	26.88	30.86	2.19	0.18	0.05	69.07
185-196	11	5.06 XIIBmb	108	2.5Y 4/3	8.1	0.53	8.33	32.67	7.41	4.4	2.78	5.1	16.71	30.93	18.87	10.33	1.5	0.18	0.05	69.07
196-210	14	7.42 XIIBmb	144	2.5Y 4/4	8.1	0.48	7.58	29.66	5.79	5.33	3.94	6.02	13.82	35.44	22.32	11.73	1.21	0.15	0.03	64.56
210-225	15	7.2 Bmb	144	2.5Y 4/4	8.1	0.41	9.25	31.98	4.4	4.63	4.63	4.4	16.17	33.79	20.6	11.56	1.34	0.21	0.08	66.21
225-240	15	6.15 Bmb	144	2.5Y 4/4	8.1	0.5	12.9	38	6.26	6.95	5.1	5.33	15.94	22.42	13.56	6.98	1.48	0.22	0.18	77.58
240-250	10	3.7 Bmb	144	2.5Y 6/4	8.2	0.37	18.5	32.9	7.41	6.72	5.79	7.41	15.06	24.71	17.29	5.65	1.38	0.25	0.14	75.29
250-260	10	2.96 XIIIBmb	216	2.5Y 6/4	8.3	0.37	18.0	25.02	5.79	6.72	7.18	8.57	14.27	32.45	27.37	1.56	1.25	0.23	0.04	67.55
260-268	8	3.2 XIIIBmb	180	2.5Y 5/4	8.3	0.4	17.5	38.69	8.11	6.49	6.02	5.79	21.34	13.56	9.81	2.55	0.96	0.16	0.08	86.44
268-276	8	2.24 XIIIBmb	180	2.5Y 5/4	8.2	0.28	17.4	42.63	8.57	6.95	4.63	5.1	16.73	15.39	10.6	3.31	1.33	0.11	0.04	84.61
276-284	8	3.8 XIIBmb	144	2.5Y 4/4	8.2	0.38	14.5	45.65	9.73	5.79	3.71	3.71	16.13	15.28	10.72	2.96	1.34	0.18	0.08	84.72
284-294	10	2.58 XIIBmb	144	2.5Y 4/4	8.1	0.43	12.1	55.84	14.3	8.11	2.32	1.85	14.22	3.29	1.63	0.89	0.56	0.17	0.04	96.71
294-310	6	2.58 XIVC	8	0.41	8.17	37.69	13.6	6.02	3.24	0.93	15.51	2.94	1.12	1.02	0.58	0.17	0.05	0.17	0.05	97.06
310-325																				
325-340																				

Weighted Average 0.564060 168.09 C6..C34
 Total depth 298 B6..B34
 Weighted Average 0.7575 33.33 C6..C12
 Upper loess, 44 B6..B12
 upper 50 cm
 Weighted Average 0.560654 119.98 C13..C29
 Upper loess, 214 B13..B29
 below 50 cm
 Weighted Average 0.3695 14.78 C30..C34
 Lower loess 40 B30..B34

*Cross product refers to the change in depth multiplied by the Percentage Organic matter content.

Analytical Data for Kipp, Station K4.8

Depth cm	Change in depth product	*Cross Horizon (V(4C))	Horizon	Hurst	Colour	pH	OC %	Carb %	<2µ	2-4µ	8-4µ	16-8µ	31-16µ	62-31µ	2000-62µ	125-250µ	250-500µ	500-1000µ	1000-3000µ	Silt-Cl /	
0-4	4	5.8	IAH	120	10YR 5/3	7.1	1.45	4.75	22.71	4.4	5.1	3.01	5.79	16.36	42.63	30.99	7.95	2.74	0.51	0.44	57.37
4-18	14	15.54	Bm	160	10YR 5/4	7.95	1.11	4.67	23.17	1.39	3.71	3.01	5.56	13.05	50.11	31.57	14.71	3.46	0.21	0.16	49.89
18-33	15	12.75	Bm	160		8	0.85	5.75	17.61	3.24	2.78	2.55	5.79	5.06	62.97	31.09	28.16	3.36	0.18	0.18	37.03
33-34	1	0.77	IIbmb1	160	10YR 4/2	8	0.77	6.58	14.83	2.09	2.55	2.78	4.86	10.22	62.67	30.43	28.14	3.9	0.13	0.07	37.33
34-50	16	11.52	Bm2b1	160	10YR 5/4	8.3	0.72	7	18.54	2.78	3.71	3.01	3.94	10.74	57.82	27.53	26.37	3.58	0.19	0.15	42.18
50-58	18	12.78	Bm2b1	160		8	0.71	8	27.8	4.87	4.17	3.01	3.94	10.74	45.51	24.7	16.38	3.8	0.35	0.28	54.49
58-71	13	2.07	IIIAhb2	48	10YR 3/2	8.3	0.69	7.5	24.09	4.63	3.94	2.32	3.94	8.84	52.24	41.3	5.53	4.82	0.32	0.14	47.76
71-82	11	8.91	Bmb2	160	10YR 5/4	8.3	0.81	6.5	26.63	3.48	2.78	3.47	4.17	10.07	49.38	22.5	23.26	4.22	0.24	0.1	50.52
82-93	11	7.77	Bmb2	160		8.45	0.7	7.17	28.03	5.33	4.17	1.16	4.63	9.72	48.96	21.59	20.43	4.56	0.28	0.14	50.51
93-97	4	3.72	IVAhb3	64	10YR 4/2	8.25	0.91	4.92	23.4	7.18	5.56	2.32	6.02	9.07	37.64	19.21	15.2	2.66	0.23	0.34	62.36
97-107	10	9.6	Bmb3	120	10YR 5/3	8.3	0.96	6.92	32.21	6.02	3.71	3.24	4.4	11.09	40.03	22.53	14.99	2.04	0.14	0.43	59.97
107-118	11	11.11	Bmb3	120		8.25	1.01	6.75	31.51	6.72	4.4	3.94	4.87	12.13	35.92	20.44	11.38	1.61	0.2	0.17	63.15
118-121	3	3.21	VAhb4	64	10YR 4/2	8.1	1.07	8.33	31.97	6.72	4.4	3.94	4.87	12.13	35.92	20.44	11.38	1.81	0.13	0.16	64.08
121-131	10	10.4	Bmb4	160	10YR 5/4	8.3	0.75	5.92	21.08	4.4	1.16	4.4	4.64	13.4	50.92	35.39	14.26	1.52	0.17	0.09	59.72
131-145	14	10.5	Bmb4	160		8.25	0.71	7.08	27.34	3.94	4.17	4.4	4.64	13.4	50.92	35.39	14.26	1.52	0.17	0.11	56.87
145-160	15	11.4	Bmb4	160		8.2	0.5	8.33	26.18	4.87	2.78	5.1	5.56	10.99	43.13	39.4	1.72	1.73	0.16	0.05	51.8
160-175	15	10.65	Bmb4	160		8.1	0.59	8.67	39.55	3.48	4.87	1.85	4.17	11.25	48.2	31.54	13.91	2.54	0.16	0.12	63.42
175-190	15	7.5	Bmb4	160	10YR 5/4	8	0.55	8.33	34.99	5.56	6.02	2.78	3.94	10.13	36.58	16.82	16.33	3.08	0.33	0.13	73.53
190-203	13	10.03	VC	160	10YR 5/4	8.1	0.59	10.08	41.7	7.65	5.1	3.24	4.17	11.67	26.47	11.27	11.44	3.22	0.41	0.46	72.83
203-220	17	12.8	VC	160		8.1	0.48	8.67	39.55	8.11	5.79	4.63	3.71	10.8	27.11	11.83	10.7	3.4	0.72	0.2	74.35
220-240	20	9.6	VC	160		8.1	0.48	9	44.26	6.95	5.79	3.01	3.94	10.4	25.65	10.86	10.17	3.93	0.49	0.1	71.78
240-260	20	9.6	VC	160		8.15	0.48	8.75	41.01	5.56	7.18	2.55	4.17	11.31	28.22	12.75	10.31	4.37	0.13	0.17	66.43
260-280	20	9.2	VC	160		7.85	0.46	9.17	33.37	5.79	6.26	2.32	4.63	14.06	33.57	16.53	12.57	4.37	0.15	0.04	70.61
280-300	20	11.2	VC	160		8	0.56	9.58	37.34	4.63	4.63	6.49	9.73	17.79	39.39	26.76	0.28	2.06	0.15	0.04	70.61
300-320	20	13.6	VC	160		8	0.68	13.25	37.54	8.34	5.79	5.33	7.88	19.54	15.58	13.68	0.44	0.81	0.22	0.43	84.42
320-340	20		VIC	160	10YR 3/2	8	0.65	11.25	60.24	15.29	6.02	4.63	1.62	8.88	3.32	2.48	0.23	0.39	0.14	0.08	96.68
340-360					10YR 7/2																

Weighted Average 0.70326 239.11 c6..c11
 Total 340 b6..b31
 Weighted Average 0.9276 46.38 c6..c10
 Upper loss, upper 50 cm 50 b6..b10
 Weighted Average 0.66458 197.73 c11..c11
 Upper loss, below 50 cm 290 b11..b31
 Weighted Average N/A
 Lower loss

*Cross product refers to the Change in depth multiplied by the percent organic matter content

Analytical Data for Kipp, Station K4.10

Depth cm	Change in Depth	*Cross product	Horizon	Hurst V(4C)	Colour	pH	OC %	Carb %	<2µ	2µ	4- 8µ	8- 16µ	16- 31µ	31- 62µ	62- 125µ	125- 250µ	250- 500µ	500- 1000µ	1000- 2000µ	Silt Clay	
0-8	8	8.64	IAH	120	10YR 5/3	7.3	1.08	7.75	19	2.78	5.1	4.87	6.02	17.84	44.39	28.48	12.69	2.16	0.7	0.33	55.61
8-18	10	7.6	Ba	160	10YR 5/4	7.6	0.76	9.33	21.78	2.32	5.09	2.55	9.27	15.72	43.27	33.82	6.62	1.76	0.54	0.53	56.73
18-28	10	8.2	Ba	160		8	0.82	9.17	25.72	4.86	3.94	4.87	5.33	19.77	35.51	32.6	1.11	1.37	0.23	0.2	64.49
28-37	9	7.47	IIAhb1	96	10YR 4/3	8	0.83	7.58	29.66	4.87	4.63	4.63	7.16	15.68	33.35	30.34	1.21	1.28	0.3	0.22	66.65
37-55	18	16.2	Ba1b1	160	10YR 5/4	8.2	0.9	9.25	31.97	6.02	5.1	3.71	4.62	14.62	31.95	21.35	10.25	1.69	0.52	0.24	66.05
55-75	20	16.2	Ba1b1	160		8.4	0.81	14.5	37.07	6.49	4.17	5.56	5.79	14.32	26.6	15.52	8.2	1.79	0.62	0.47	73.4
75-90	15	11.7	Ba2b1	160	10YR 5/4	8.45	0.78	12.1	40.08	7.65	6.02	3.94	4.87	14.16	23.28	12.07	7.8	2.49	0.55	0.37	76.72
90-105	15	10.05	Ba2b1	160		8.4	0.66	12.5	38	6.02	6.49	2.55	7.18	14.38	29.78	22.75	2.35	3.83	0.54	0.31	70.22
105-120	15	9.9	Ba2b1	160		8.35	0.88	9.58	35.22	6.26	4.87	4.4	4.4	13.98	31.11	20.31	5.27	4.4	0.66	0.47	68.89
120-135	15	13.2	Ba2b1	160		8.45	0.6	9.67	32.2	5.79	5.56	5.1	5.1	15.19	31.06	15.63	9.41	3.18	2.79	0.05	68.94
135-150	15	9	Ba2b1	160		8.4	0.51	8.17	27.8	5.56	3.71	3.94	7.41	17.21	34.37	22.25	9.86	2.04	0.18	0.04	65.63
150-165	15	7.65	Ba2b1	160	10YR 5/4	8.4	0.45	6.92	27.11	4.63	2.78	5.56	7.88	16.94	35.1	23.08	9.83	2.03	0.12	0.04	64.9
165-180	15	6.75	Ba3b1	160		8.25	0.48	7.58	25.49	4.4	2.08	4.87	11.58	21.18	30.4	24.29	5.43	0.57	0.05	0.05	69.6
180-195	15	7.2	Ba3b1	160		8.2	0.54	7.75	24.33	4.17	4.4	4.17	12.51	21.02	29.4	28.74	0.06	0.51	0.05	0.04	70.6
195-210	15	8.1	Ba3b1	160		8.1	0.64	5.17	21.32	4.4	4.4	4.86	13.21	22.76	29.05	26.48	2.18	0.3	0.06	0.03	70.95
210-220	10	6.4	IIIAhb2	96	10YR 4/3	8.1	0.6	8.17	20.85	3.48	3.46	6.26	13.9	25.53	26.5	22.94	3.19	0.28	0.06	0.03	73.5
220-233	13	7.8	IIIAhb2	96		8.2	0.6	12.9	22.24	4.17	5.1	7.88	19.46	24.87	16.28	13.66	2.01	0.47	0.09	0.05	83.72
233-250	17	10.2	Ba1b2	144	10YR 6/3	8.2	0.61	15.6	22.24	5.79	6.03	9.27	18.07	27.75	10.85	10.32	0.34	0.12	0.06	0.01	89.15
250-265	15	9.15	Ba1b2	144		8.2	0.55	15.1	33.36	7.41	3.25	7.88	10.43	22.63	13.04	13.16	1.22	0.43	0.09	0.14	84.36
265-280	15	8.25	Ba1b2	144	10YR 5/4	8.1	0.54	13.0	41.94	9.5	7.88	3.94	6.72	18.6	11.42	9	1.6	0.62	0.14	0.06	88.58
280-295	15	8.1	Ba2cab2	160		8	0.5	13.4	47.73	19.2	16.2	7.64	1.39	7.32	0.47	0.33	0.04	0.07	0.02	0.01	99.53
295-310	15	7.5	Ba2cab2	160		2.5Y 3/2	7.9	0.53	13.1	55.14	16.2	12.5	5.1	2.55	7.57	0.91	0.56	0.1	0.06	0.05	99.09
310-325	15		IVC			2.5Y 4/4															

Weighted Average 0.662129 205.26 c6..c27
 Total 310 b6..b27

Weighted Average 0.874727 48.11 c6..c10
 Upper loess, upper 50 cm 55 b6..b10

Weighted Average 0.643548 99.75 c11..c20
 Upper loess, below 50 cm 155 b11..b20

Weighted Average 0.574 57.4 c21..c27
 Lower loess 100 b21..b27

*cross product refers to the Change in depth multiplied by the percent organic matter content

Analytical Data for Kipp, Station K4.12

Depth cm	Change in depth product	*Cross Horizon	Colour	PH	OC %	Carb %	<2μ	4μ	8μ	16μ	31μ	62μ	2000 62μ	125μ 250μ	250- 500μ	500- 1000μ	1000- 2000μ	Silt + Clay	
0-12	15.96	IaH	96 10YR 4/3	7.3	1.31	7.83	23.73	5.3	3.54	0	11.8	12.97	42.59	0.09	0.62	3.4	16.98	21.5	57.41
12-25	12.48	Bt	120 10YR 5/3	7.6	0.96	9	31.06	5.05	4.55	3.03	4.55	14.8	36.96	0.43	0.33	5.48	11.69	19.03	63.04
25-40	15.15	IaHb1	64 10YR 4/2	7.8	1.01	8.92	35.35	6.57	5.81	4.04	3.54	13.77	30.92	0.42	0.3	2.91	12.24	15.05	69.08
40-55	13.5	Bmb1	96 10YR 4/3	7.8	0.9	6.08	37.77	6.49	5.56	2.32	4.63	5.24	37.99	0.19	0.62	3.16	16.08	17.94	62.01
55-65	8.7	Bm2b1	120 10YR 5/3	7.9	0.87	7.67	36.86	6.31	4.8	4.55	4.8	12.43	30.25	0.24	0.33	2.81	12.1	14.77	69.75
65-80	12	Bm2b1	120	8.1	0.8	9.58	39.89	7.93	4.04	4.04	3.79	12.04	28.37	0.14	0.28	2.98	11.06	13.91	71.63
80-95	8.25	Bm2b1	120	8.1	0.55	11.0	39.89	7.32	4.8	3.28	4.29	14.92	25.5	0.09	0.2	3.01	9.98	12.22	74.5
95-110	8.1	Bm2b1	120 10YR 5/4	8.15	0.54	12.2	40.15	6.82	6.82	3.03	2.02	17.37	21.79	0.05	0.25	3.43	9.16	10.9	76.21
110-120	6.3	Bm3b1	160 10YR 5/4	8.2	0.63	10.1	38.63	7.83	5.56	3.03	2.27	11.6	31.08	0.08	0.44	4.96	12.45	13.15	68.92
120-135	7.2	Bm3b1	160	8.2	0.48	11	41.91	8.33	6.82	3.54	2.2	11.5	25.88	0.09	0.29	4.03	12.74	8.73	74.3
135-150	6.45	Bm3b1	160	8.25	0.43	9.5	38.38	6.82	6.31	3.79	2.78	11.63	30.29	0.02	0.16	4.45	13.62	12.04	69.71
150-165	5.55	Bm3b1	160	8.3	0.37	9.83	36.36	6.57	4.8	3.03	3.54	12.1	33.6	0.05	0.1	7.2	14.37	11.88	66.4
165-180	5.55	Bm3b1	160	8.35	0.37	9.5	36.11	6.06	3.79	5.3	3.03	13.77	31.94	0.02	0.19	6.05	12.82	12.86	68.06
180-195	5.1	Bm3b1	160	8.4	0.34	9	38.38	6.57	6.31	2.78	3.54	19.65	22.77	0.01	0.11	3.81	9.63	9.21	77.23
195-205	3.7	Bm3b1	160	8.4	0.37	9.5	39.89	7.58	4.8	7.07	3.79	13.7	23.17	0.02	0.15	2.06	7.52	13.42	76.83
205-215	3.6	III Bmb2	160 10YR 5/4	8.3	0.36	14.4	54.79	9.85	7.58	2.53	4.55	15.4	5.3	0.08	0.11	0.64	1.64	2.83	94.7
215-230	6.9	Bmb2	160	8.4	0.46	11.0	58.32	12.3	7.32	2.27	3.79	9.08	6.85	0.13	0.19	0.73	1.97	3.83	93.15
230-245	5.85	Bmb2	160	8.3	0.39	11.9	58.77	10.8	8.59	2.53	3.54	13.1	8.51	0.03	0.07	0.44	1.29	6.78	91.39
245-255		IV Bmb2	10YR 3/1	8.1	0.4	10.3	62.87	13.3	6.31	2.78	3.03	8.91	2.72	0.04	0.05	0.03	0.48	1.8	97.28
255-265		Bmb2	10YR 4/3	7.75	0.48	8.42	64.13	10.3	5.81	3.03	2.27	11.37	2.53	0.03	0.07	0.19	0.44	1.8	97.47

Weighted Average 0.613632 150.14 C6...C23
Total 245 B6...B23

Weighted Average 1.038 57.09 C6...C9
Upper loess, 55 B6...B9
upper 50 cm

Weighted Average 0.512666 76.9 C10...C20
Upper loess, 150 B10...B20
below 50 cm

Weighted Average 0.40875 16.35 C21...C23
Lower loess 40 B21...B23

*Cross product refers to the Change in depth multiplied by the Percent organic matter content

Analytical Data for Kipp, Station K4.15

Depth Cm	Change in depth	*Cross product	Horizon	Hurst (v/4c)	Colour	pH	OC %	Carb %	<2µ %	4- 2µ	8- 4µ	16- 8µ	31- 16µ	62- 31µ	200 62µ	250µ 125µ	250µ 125µ	500µ 250µ	500- 1000µ	1000- 2000µ	Silt + Clay	
0-5	5	9.1	Iah	96	10YR 4/3	7.1	1.82	9.67	29.89	1.62	5.1	3.94	5.79	11.1	42.53	25.63	10.67	3.24	1.85	1.34	57.47	
5-13	8	9.68	Bm	120	10YR 5/3	7.4	1.21	7.67	31.51	1.16	3.94	3.48	4.63	11.9	43.34	19.3	16.29	5.68	0.63	1.44	56.66	
13-19	6	4.2	IIAh	64	10YR 4/2	7.4	0.7	5.83	43.33	1.85	5.1	3.48	5.56	10.9	29.72	13	12.47	3.29	0.31	0.65	70.23	
19-32	13	15.08	Bmlb1	120	10YR 5/3	7.7	1.16	7.67	45.65	0	7.65	4.17	3.71	8.78	30.04	13.77	12.02	4.01	0.32	0.32	69.96	
32-46	4	14.98	Bmlb1	120	10YR 5/3	7.7	1.16	6	42.4	5.79	5.79	3.94	3.94	8.78	28.65	11.61	11.25	5.24	0.7	0.08	71.35	
46-50	4	4.52	IIIAhb2	64	10YR 4/2	7.7	1.13	5.42	39.16	4.47	5.79	5.79	3.94	4.17	9.98	31.16	13.66	12.14	4.39	0.08	68.84	
50-63	13	11.96	Bmlb2	80	10YR 5/2	7.85	0.92	6.5	39.16	4.87	5.79	5.79	3.94	4.17	9.98	31.16	13.66	12.14	4.71	0.37	0.06	67.82
63-78	15	12.3	Bm2b2	144	10YR 6/3	7.9	0.82	7.58	39.85	5.79	4.63	4.63	3.71	12.8	28.54	15.01	10.13	2.96	0.38	0.06	71.46	
78-94	16	11.2	Bm2b2	144	10YR 6/3	8.25	0.7	11.42	39.85	6.26	5.1	4.17	4.87	10.8	28.89	13.64	11.5	3.3	0.4	0.05	71.11	
94-109	15	8.55	Bm2b2	144	10YR 6/3	8.7	0.57	13.25	41.47	6.26	5.46	4.63	5.1	15.0	21.93	9.56	9.12	2.93	0.76	0.06	78.07	
109-122	13	7.15	Bm2b2	144	10YR 6/3	8.5	0.55	12.17	38.69	6.72	5.33	3.71	4.4	10.4	30.71	12.33	12.4	5.46	0.35	0.17	69.99	
122-137	15	7.35	Bm3b2	144	10YR 6/3	8.3	0.49	12.17	34.52	6.95	4.87	4.4	4.4	14.8	30.04	13.17	13.18	3.36	0.3	0.03	69.99	
137-152	15	6.6	Bm3b2	144	10YR 6/3	8.3	0.44	11.92	40.08	7.18	5.33	3.94	3.94	13.7	25.82	12.01	10.42	2.91	0.41	0.07	74.18	
152-167	15	6.3	Bm3b2	144	10YR 6/3	8.3	0.42	11.33	37.3	6.95	3.94	3.94	4.87	16.4	26.56	11.63	10.41	3.82	0.55	0.15	73.44	
167-182	15	6	Bm3b2	144	10YR 6/3	8.2	0.4	10	33.6	5.79	4.87	3.94	6.72	15.0	30.02	15.8	11.2	2.85	0.11	0.04	69.98	
182-195	13	5.85	Bm3b2	144	10YR 6/3	8.2	0.45	7.5	30.58	5.33	5.1	5.33	7.88	25.7	20.02	14.3	4.87	0.69	0.11	0.05	79.98	
195-208	13	5.59	Bm3b2	144	10YR 6/2	8.3	0.43	8	32.21	5.1	5.33	5.33	9.04	22.5	20.43	15.57	4.09	0.64	0.07	0.06	79.57	
208-225	17	8.5	Bm4b2	96	10YR 5/2	8.1	0.5	8.75	29.66	5.1	5.79	5.79	11.5	21.2	20.82	17.66	2.59	0.4	0.12	0.05	79.18	
225-241	16	8	Bm4b2	96	10YR 5/2	8.1	0.5	7.67	28.73	3.94	5.1	6.26	10.6	24.2	21.05	18.66	1.96	0.3	0.08	0.05	78.95	
241-251	10	7.1	IVAhb3	112	10YR 7/2	8.2	0.38	12.67	9.96	12.0	5.1	4.17	9.96	12.4	46.36	37.13	8.62	0.43	0.07	0.11	53.64	
251-266	15	5.7	Bmlb3	112	10YR 7/2	8.15	0.37	17.08	18.54	4.4	6.26	6.26	12.9	8.5	43.06	25.45	17.25	0.29	0.05	0.02	56.94	
266-281	15	5.55	Bmlb3	112	10YR 7/2	8.2	0.37	20.5	21.09	4.87	7.18	7.18	14.6	8.93	35.92	14.13	1.45	0.28	0.04	0.02	64.08	
281-296	15	5.55	Bmlb3	112	10YR 7/2	8.3	0.37	18.92	18.07	9.73	6.49	7.1	12.5	12.2	31.55	32.41	0.9	0.14	0.05	0.04	66.45	
296-311	15	5.55	Bmlb3	112	10YR 7/2	8.2	0.36	16.75	23.4	6.26	6.26	4.63	9.5	8.83	41.12	39.24	1.46	0.25	0.1	0.07	58.88	
311-326	15	5.4	Bmlb3	112	10YR 7/2	8.3	0.32	14.5	35.91	6.95	5.1	4.63	7.18	7.86	32.37	26.42	5.09	0.73	0.09	0.04	67.63	
326-340	14	4.48	Bmlb3	112	10YR 6/2	8.1	0.36	12.08	27.11	27.3	6.95	6.49	8.01	21.55	18	2.97	0.45	0.08	0.05	78.45		
340-352	12	4.32	VAhb4	96	10YR 6/2	8.1	0.39	8	64.88	12.7	7.18	0.93	3.24	6.74	4.29	1.43	1.43	1	0.29	0.14	95.71	
352-366	14	5.46	VIHb5	48	10YR 3/2	7.75	0.4	8.58	59.55	13.2	6.95	2.32	4.4	8.83	4.74	2.64	1.19	0.65	0.18	0.08	95.26	
366-380	14	6.88	VIHb5	48	10YR 3/2	7.7	0.43	6.57	18.77	56.7	8.8	0.23	5.79	5.59	4.05	1.54	1.03	0.52	0.46	0.1	95.95	
380-396	16	0.78	VIIAhb6	72	2.5Y 8/1	7.75	0.39	5.17	61.4	12.7	7.88	0.46	5.33	7.01	5.18	3.23	1.25	0.54	0.14	0.02	94.82	
396-398	2	6.4	Bmlb5	64	10YR 4/2	7.8	0.41	6.67	64.49	15.2	8.81	0.7	3.94	4.19	2.58	0.99	0.65	0.54	0.29	0.11	97.42	
412-428	16	6.4	Bmlb5	64	10YR 4/2	7.9	0.4	6.17	65.11	12.9	8.34	1.16	3.71	6.39	2.31	1.07	0.74	0.37	0.1	0.03	97.69	
428-440	12	5.64	Bmlb5	64	10YR 4/2	7.8	0.47	4.75	63.72	15.2	8.34	0	3.94	6.66	2.05	0.73	0.55	0.4	0.27	0.1	97.95	
440-455	15	5.7	Bmlb5	64	10YR 4/2	7.75	0.38	6.33	66.96	8.81	10.6	0.46	3.24	7.41	2.46	1.06	0.71	0.45	0.18	0.06	97.54	
455-466	15	IXC	IXC	96	10YR 6/2	7.8	0.29	7	66.96	14.6	8.57	0.46	2.09	6.06	1.26	0.5	0.37	0.22	0.1	0.07	98.74	
466-478	15	IXC	IXC	96	10YR 6/2	8.1	0.36	6.83	71.13	13.2	7.41	0.46	0.7	5.89	1.2	0.51	0.34	0.2	0.07	0.08	98.8	

Weighted Average Total	0.546725	248.76	c6..c40
Weighted Average Upper loess, upper 50 cm	1.1512	57.56	c6..c11
Weighted Average Upper loess, below 50 cm	0.498896	144.68	c12..c31
Weighted Average Lower loess	1.404521	46.52	c32..c40
		115	b32..b40

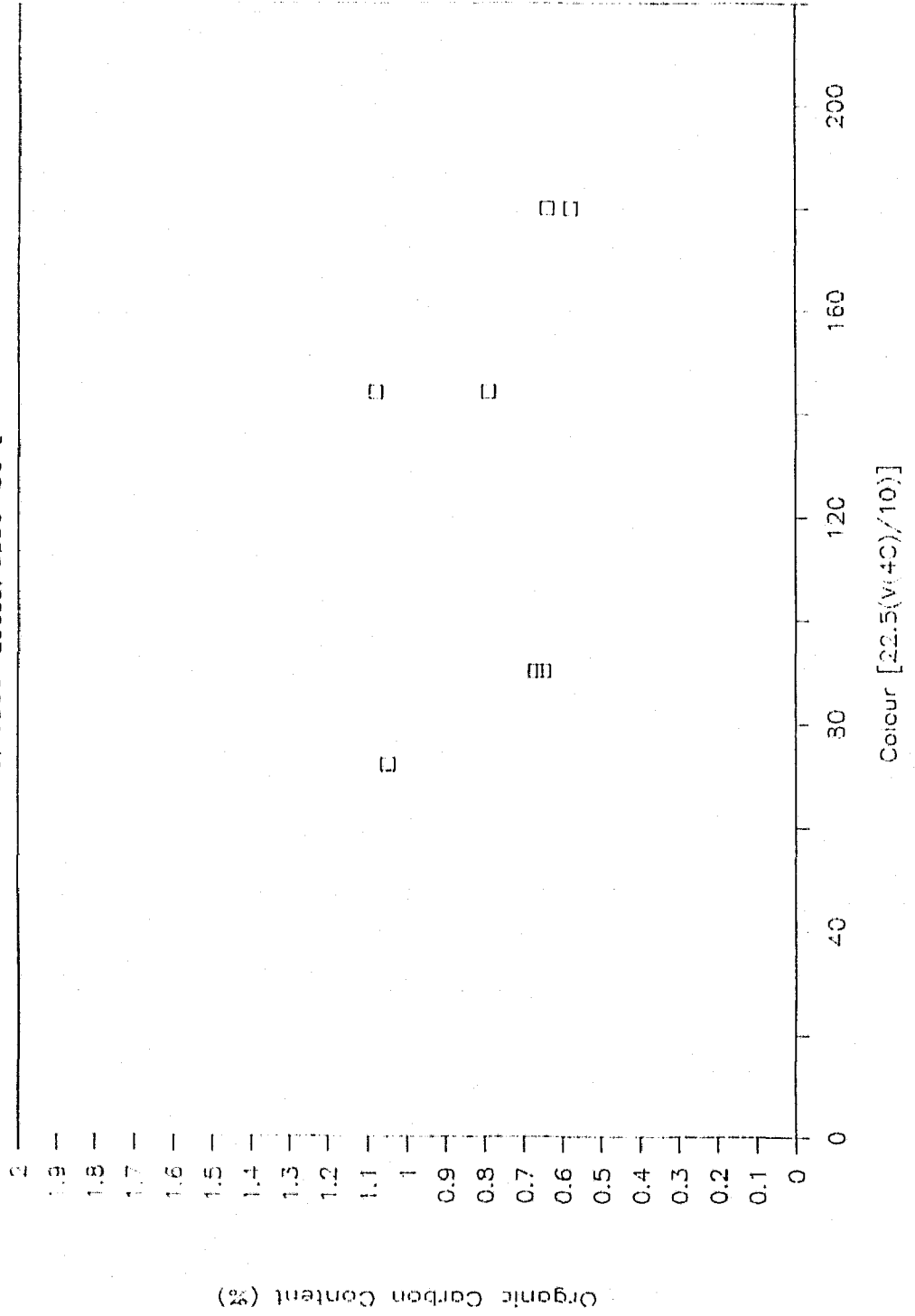
*Cross product refers to the Change in depth multiplied by the percent organic matter content

APPENDIX C

Graphs of Colour versus Organic Matter Content
by stratigraphic unit

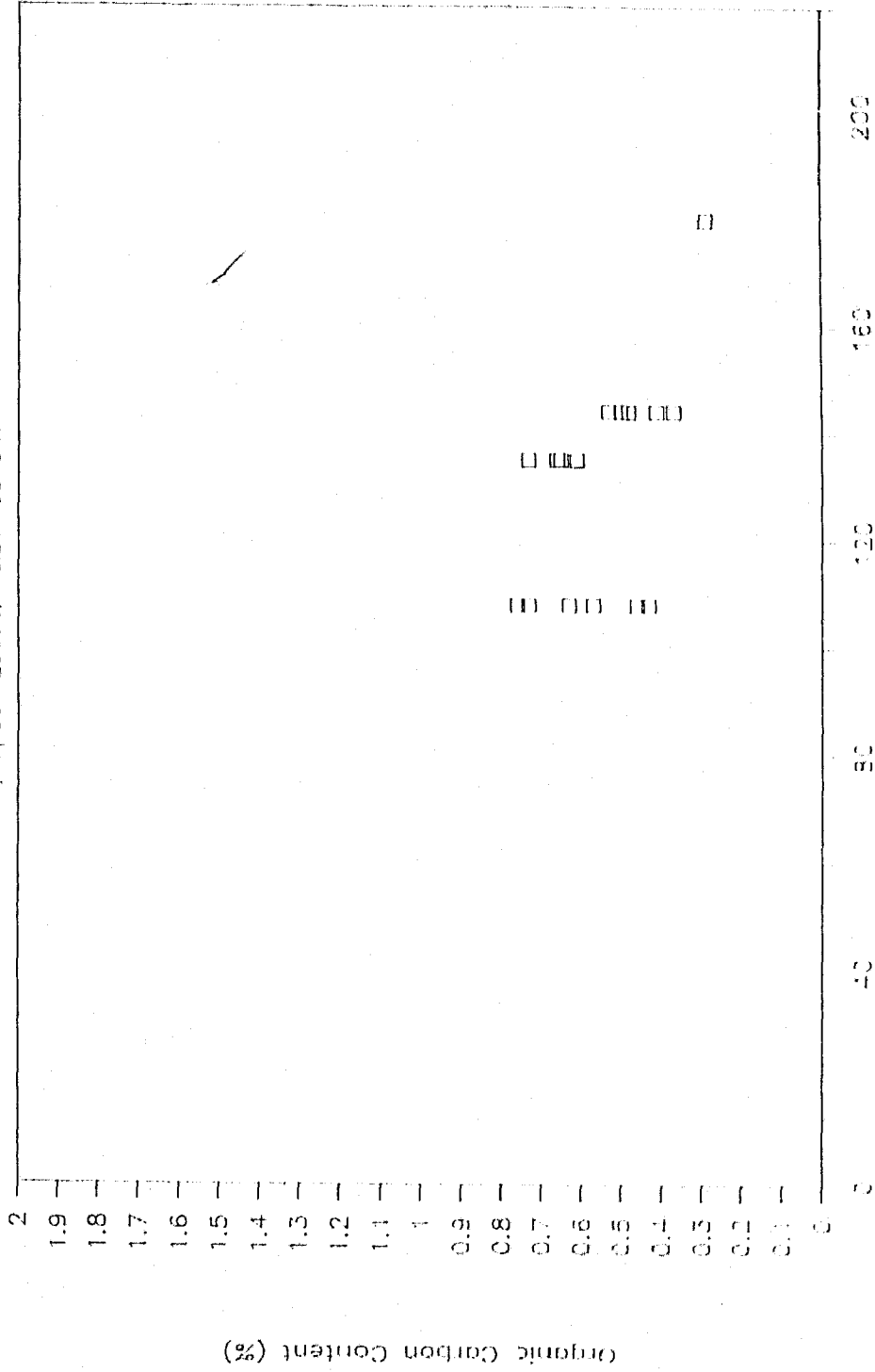
Colour vs Organic Carbon Content (%)

✓ 4.6. Upper -less. upper 50 cm



Colour vs Organic Carbon Content (%)

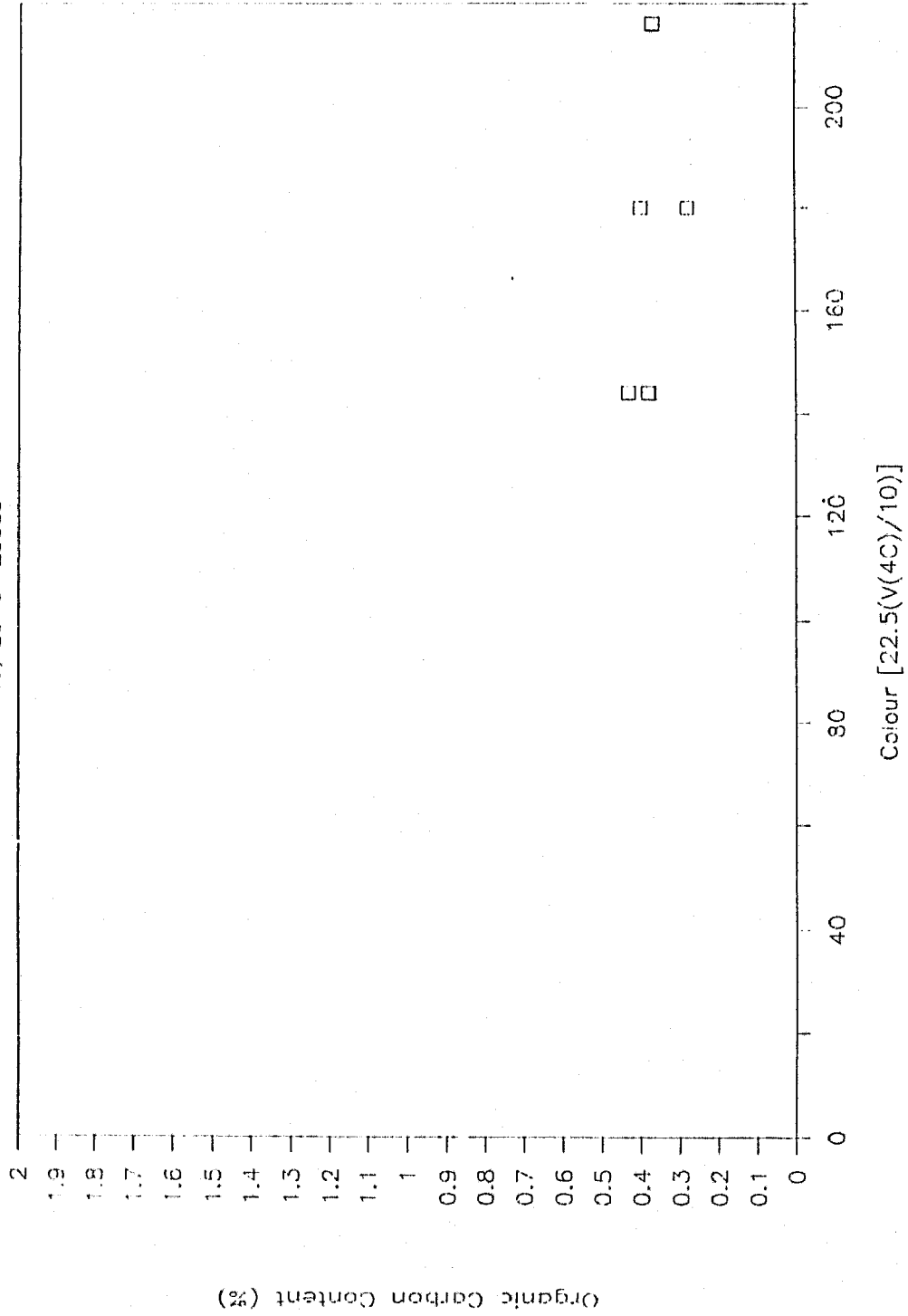
K4.6, Upper Loess, below 50 cm



Colour (0000 - 1000)

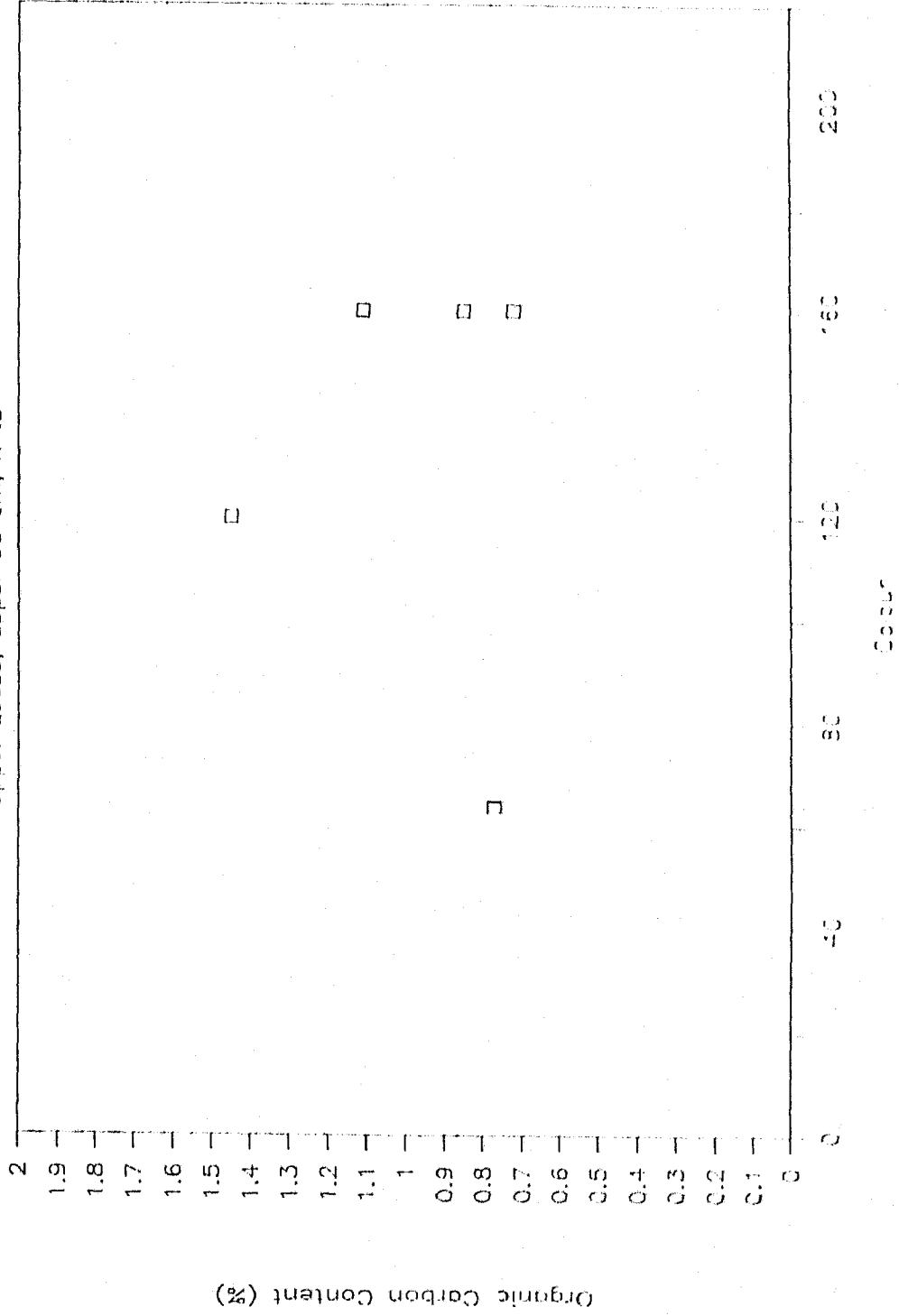
Colour vs Organic Carbon Content (%)

K4.6. Lower Loess



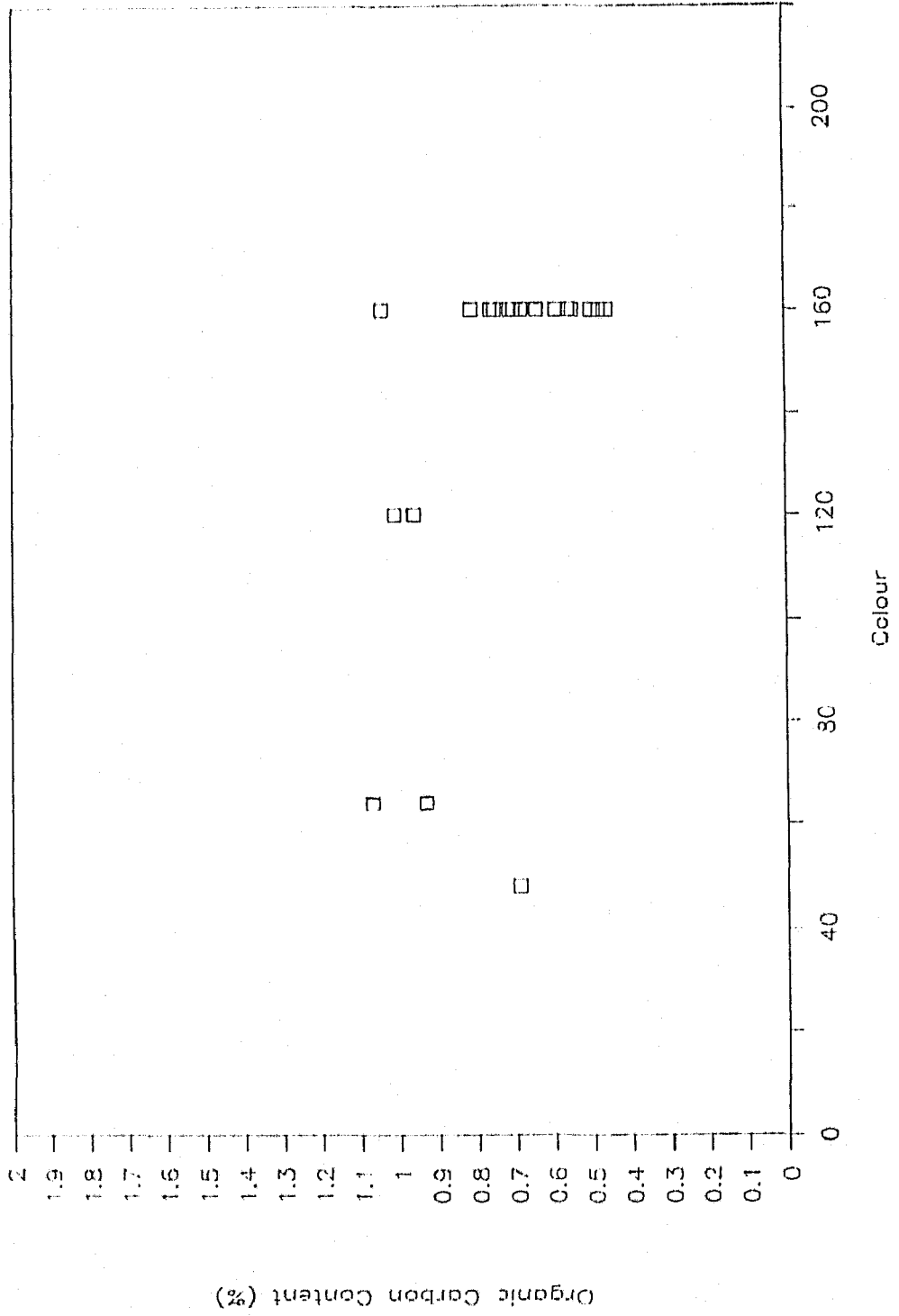
Colour vs Organic Carbon Content

Upper Loess, upper 50 cm, K4.3



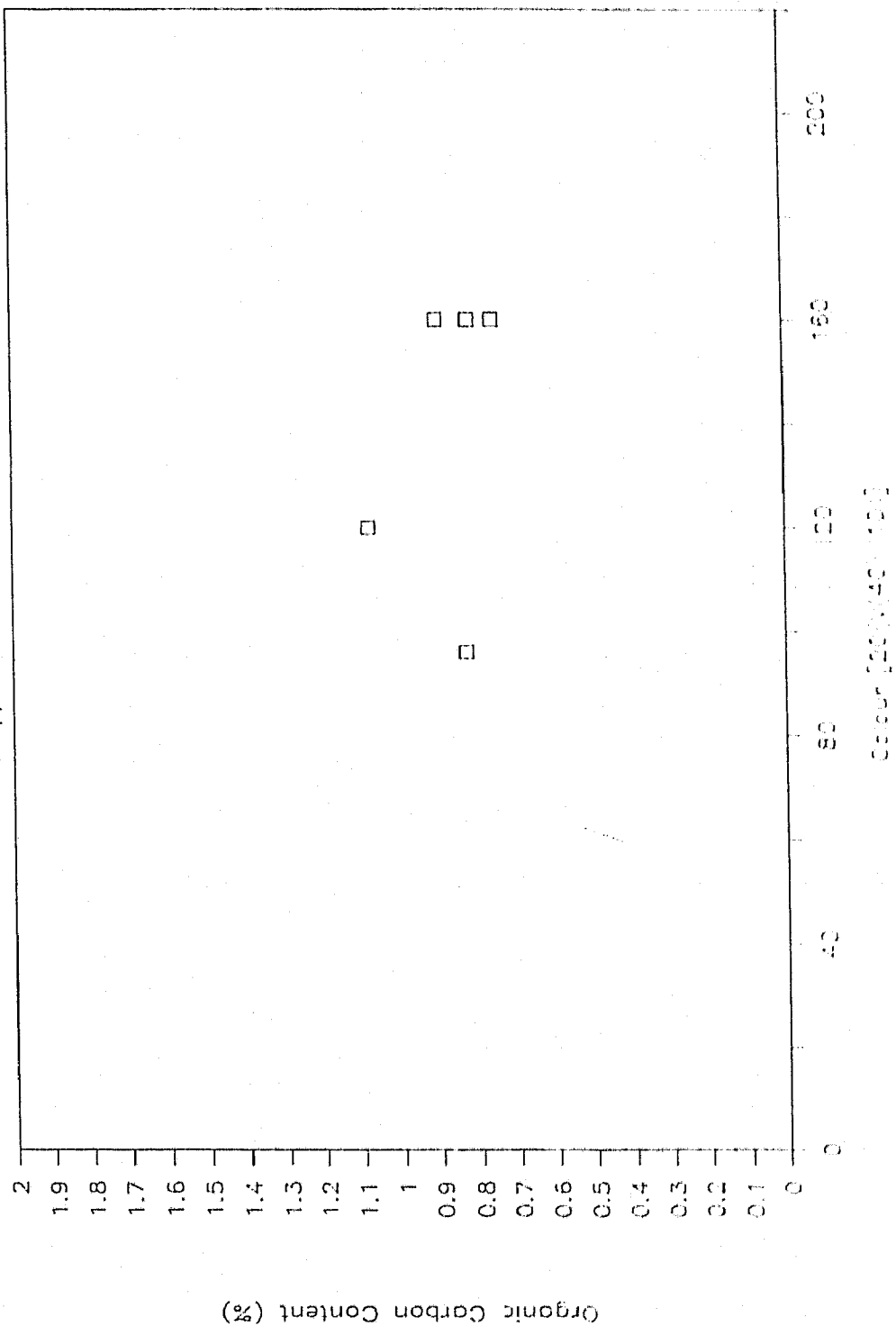
Colour vs Organic Carbon Content

Upper loess, below 50 cm, K4-B



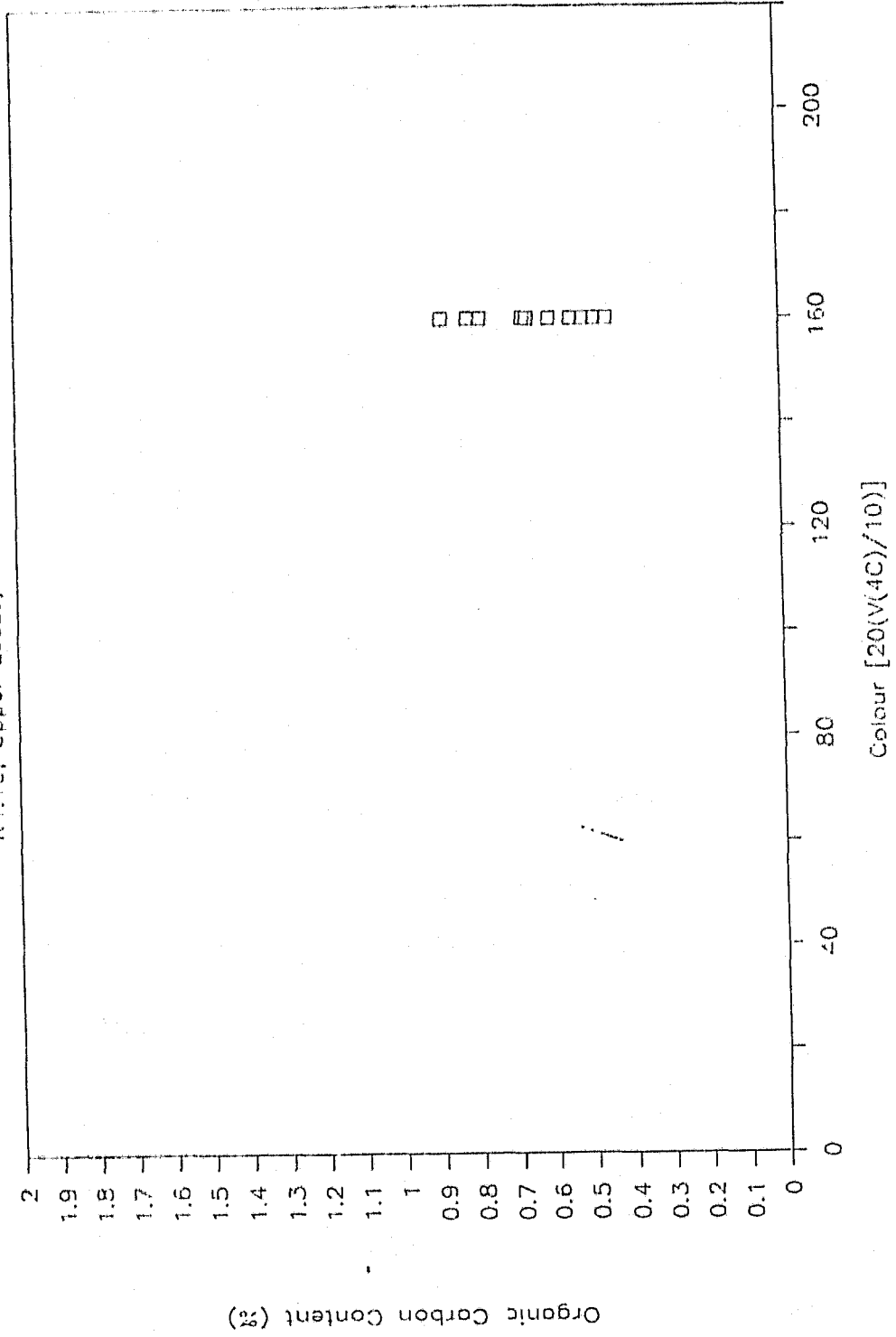
Colour vs Organic Carbon Content (%)

K4.10, Upper Loess, upper 50 cm



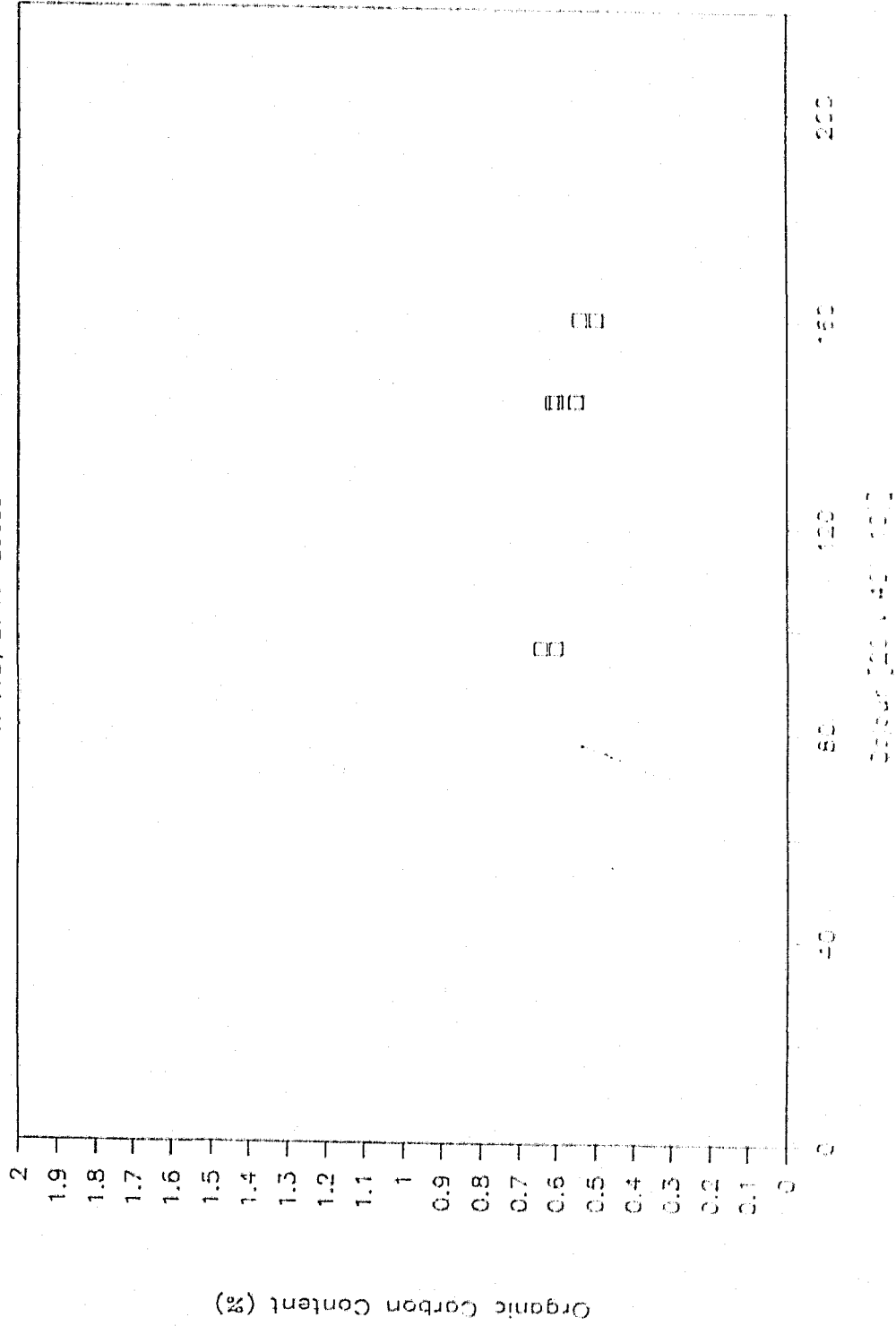
Colour vs Organic Carbon Content (%)

K4.10, Upper Loess, below 50 cm



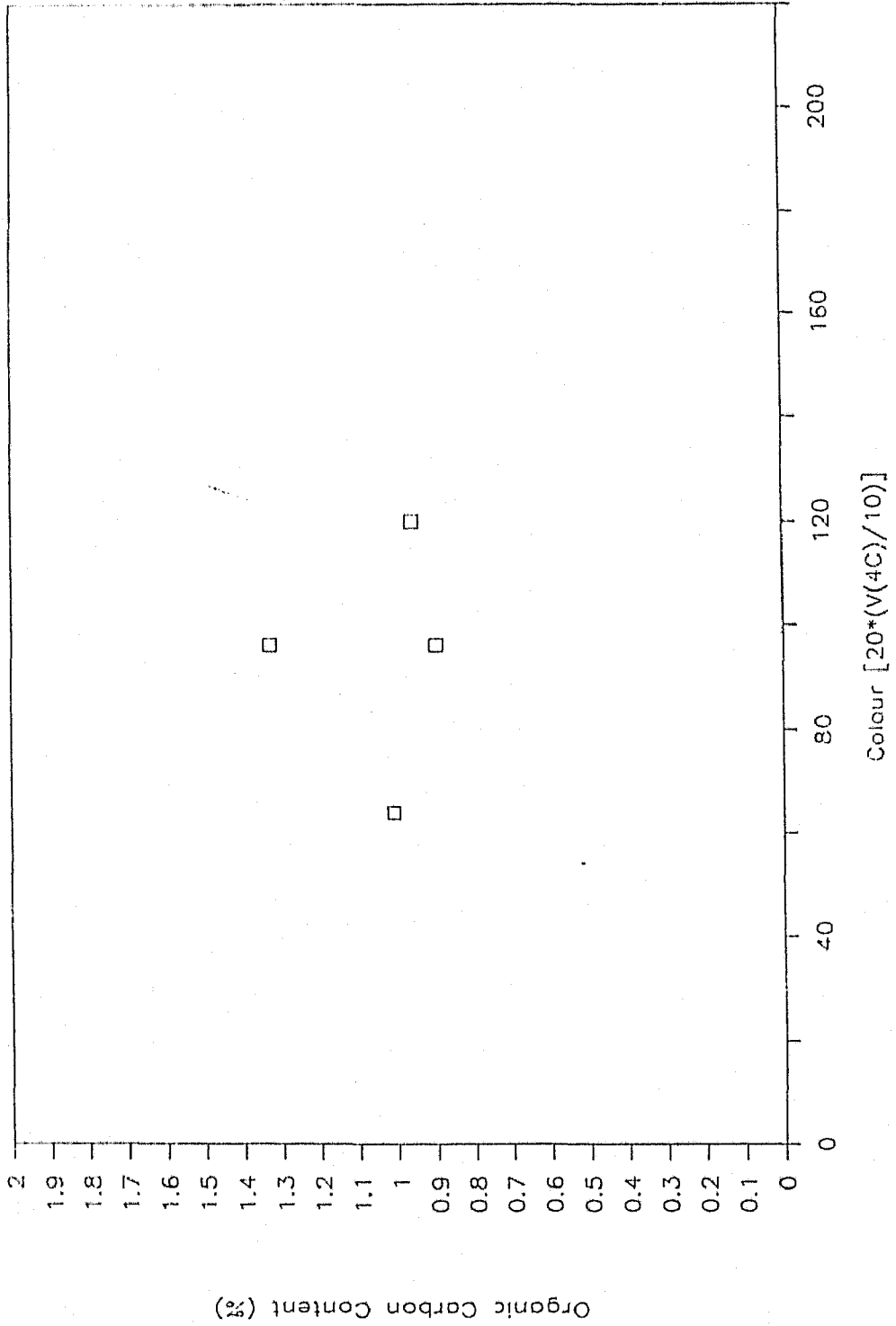
Colour vs Organic Carbon Content (%)

K4.10, Lower Loess



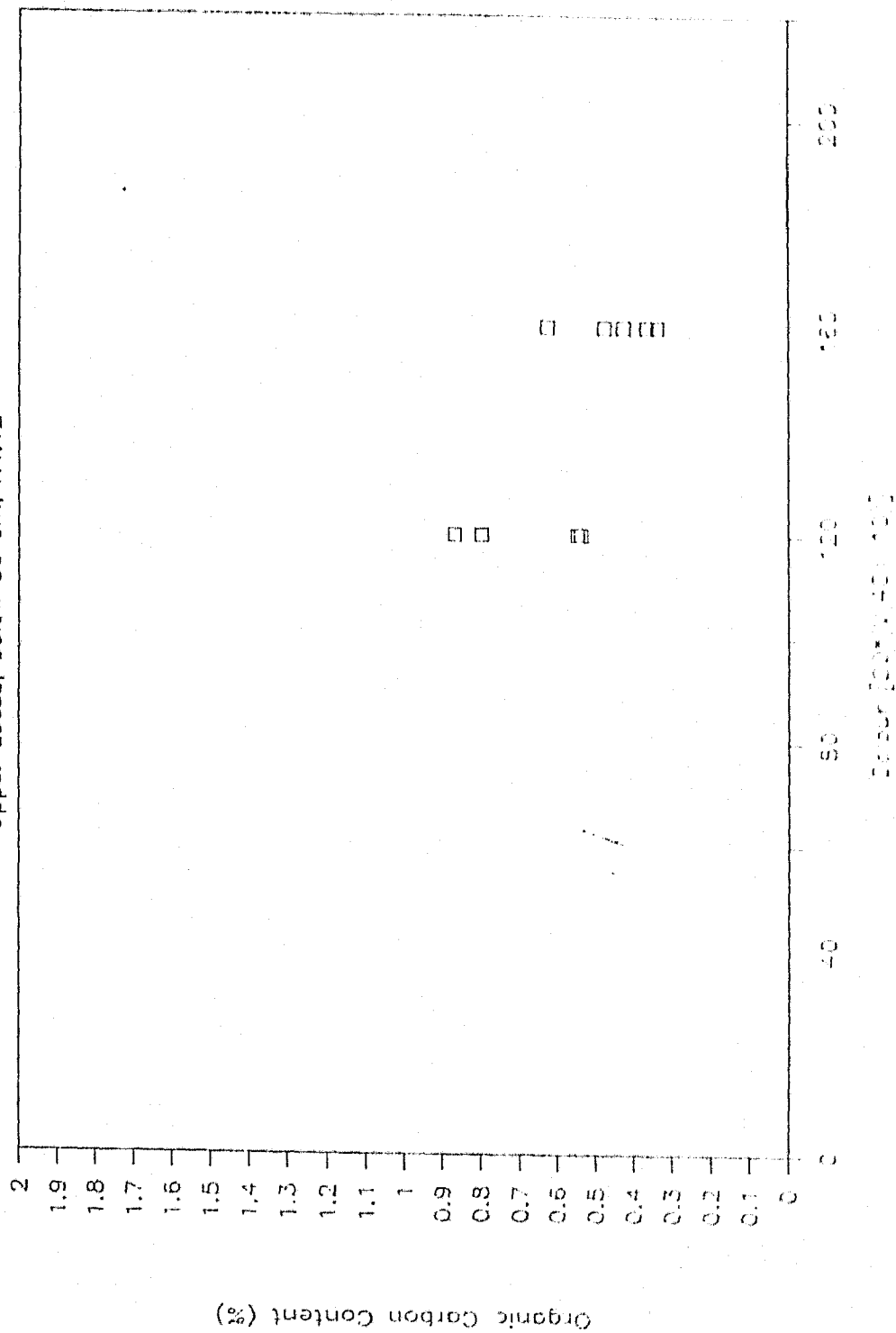
Colour vs Organic Carbon Content (%)

Upper Lcess, upper 50 cm, K4.12



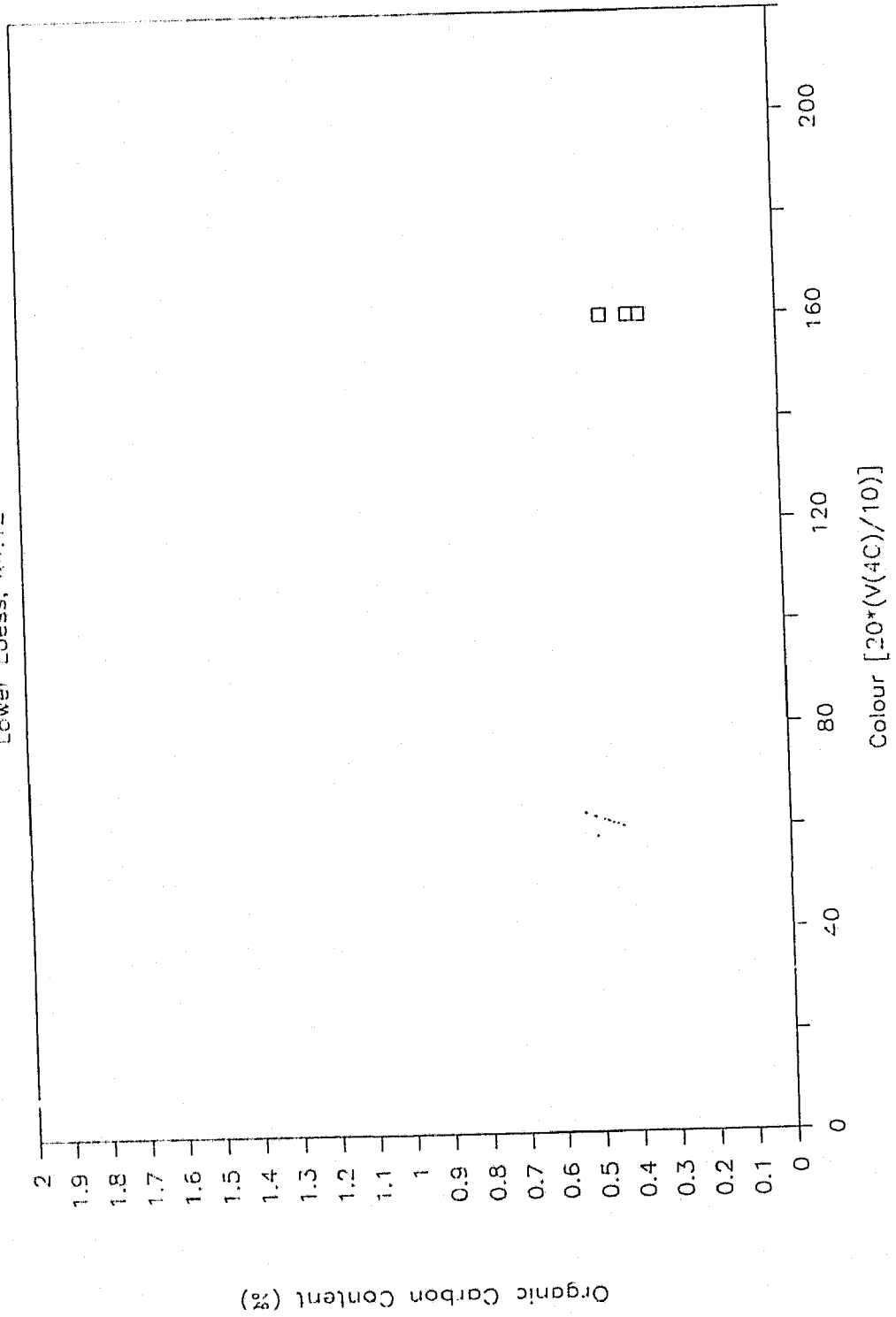
Colour vs Organic Carbon Content (%)

Upper Loess, below 50 cm, K4.12



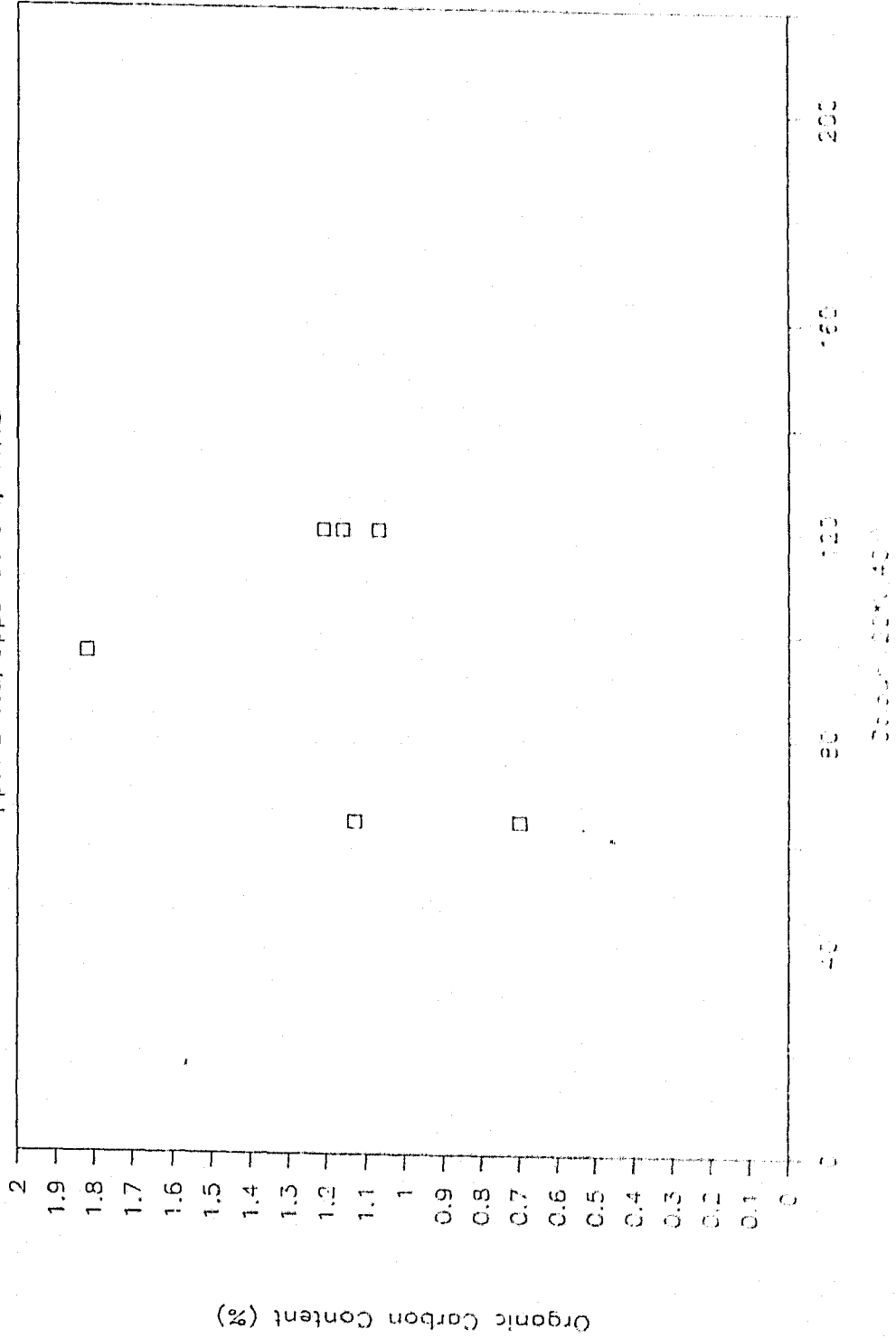
Colour vs Organic Carbon Content (%)

Lower Loess, K4.12



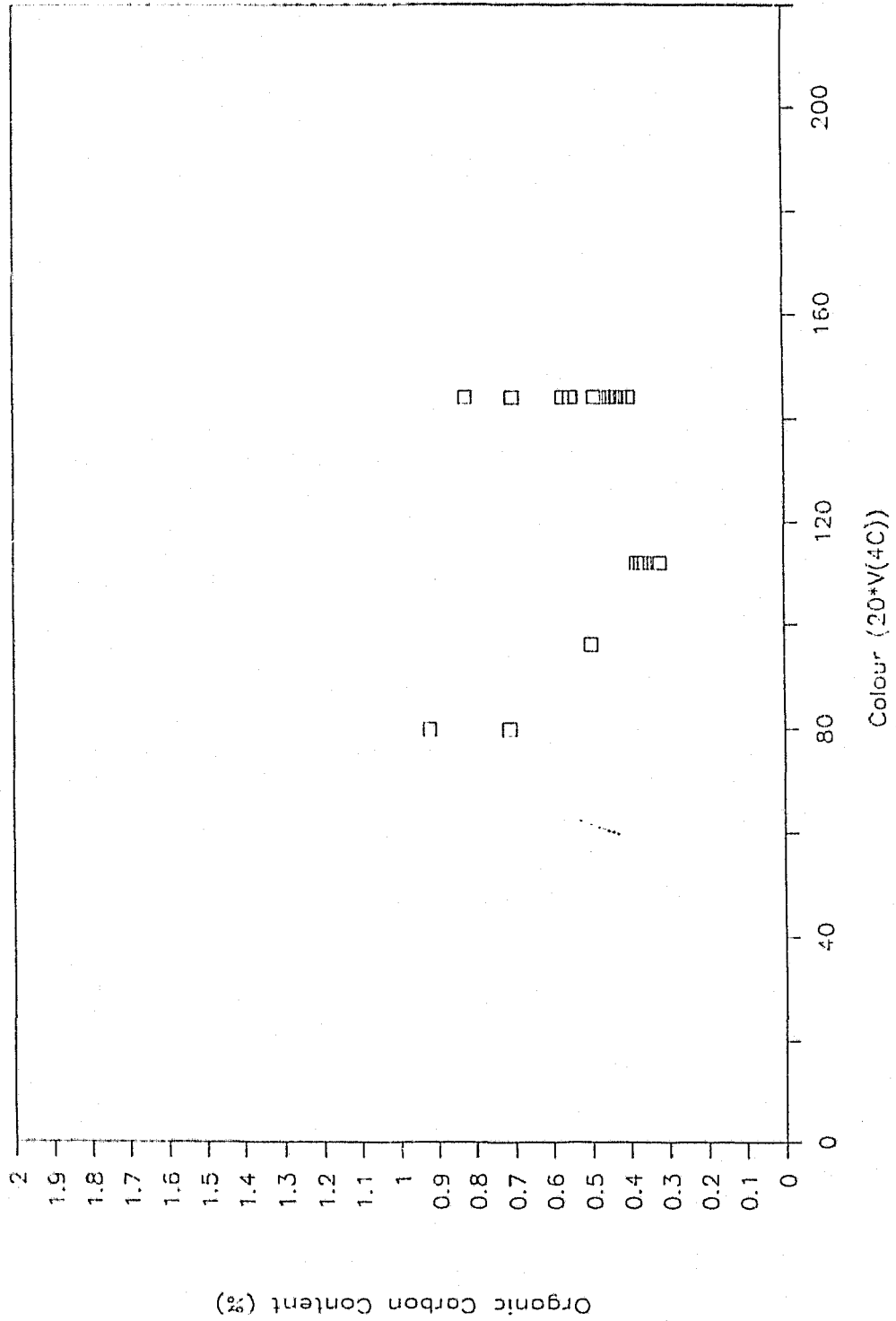
Colour vs Organic Carbon Content (%)

Upper Loess, upper 50 cm, K4.15



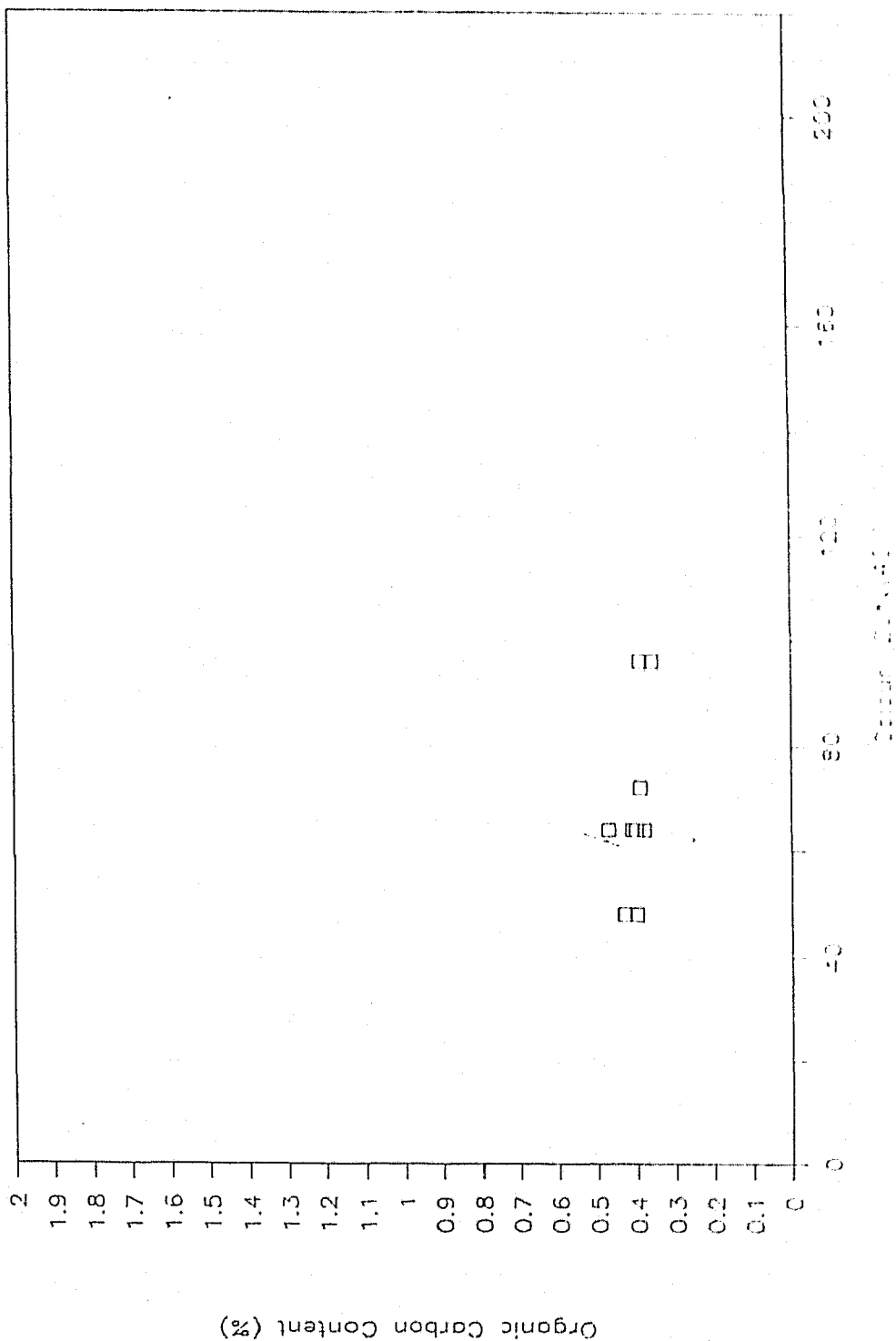
Colour vs Organic Carbon Content (%)

Upper Loess, below 50 cm, K4.15



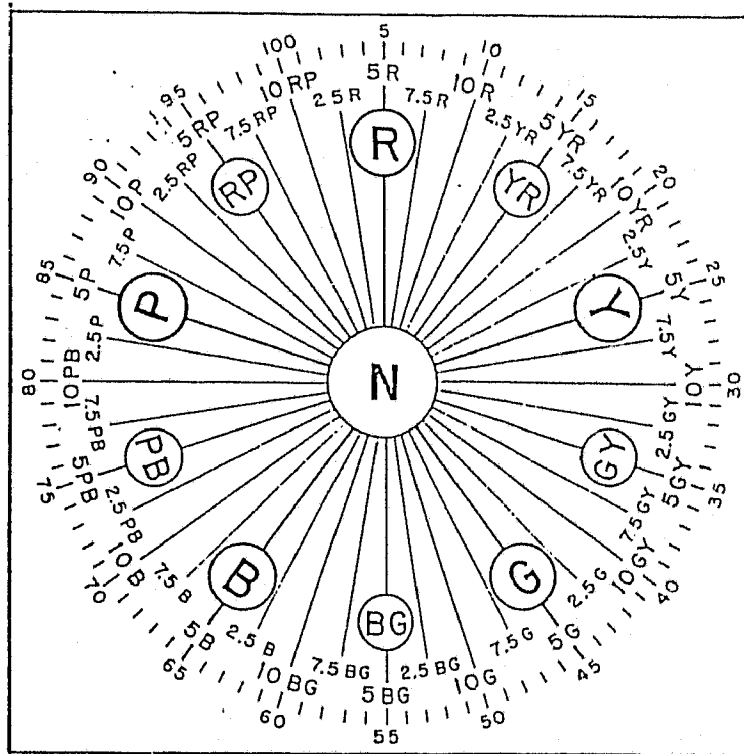
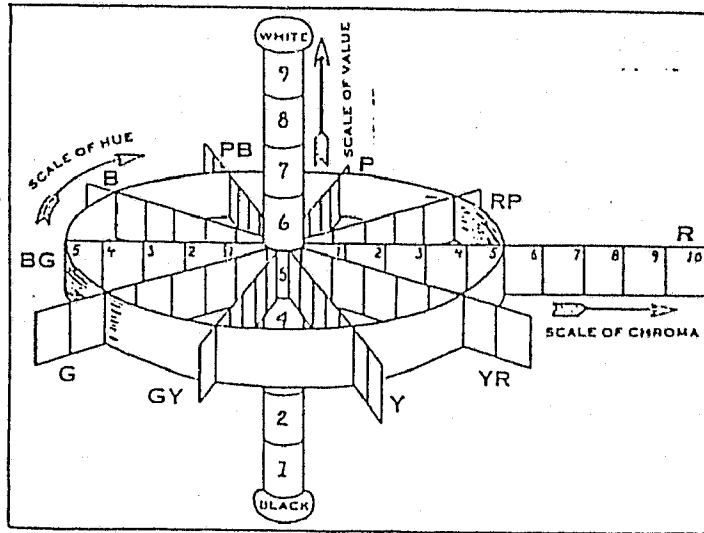
Colour vs Organic Carbon Content (%)

Lower Loess, K4.15



APPENDIX D

Munsell Colour Figures



Munsell colour figures. The Munsell System of Colour Notation as hue, value and chroma. (after Munsell 1990)

APPENDIX E

Shells

Shells

Airport Site, Lethbridge Alberta

(15-37") Bm - sandy loam

Identification by J.E. Dale, Queen's University, April 1989

Stagnicola (Stagnicola) elodes (Say, 1821)

Common *Stagnicola*

Distribution: Occurs throughout Canada below the tree line, into the United States to approximately 38°N down to 33°N in the Rocky Mountains. Most abundant species of its genus.

#'s 18+ of 9 = 27

Ecology Ubiquitous. Found in many kinds of aquatic habitats. Abundant almost everywhere in the Prairie Provinces.

Habitats

19%	large lakes
6%	small lakes
17%	permanent ponds
6%	vernal ditches
5%	roadside sloughs
7%	swamps
5%	rivers >100 ft. wide
6%	rivers 50 to 100 ft. wide
12%	rivers 25 to 50 ft. wide
13%	creeks 10 to 25 ft. wide
2%	brooks <10 ft.

Vegetation

46%	thick
23%	medium abundance
28%	sparse
2%	absent

Bottom characteristics

83%	mud
32%	sand
4%	clay
14%	gravel
11%	rock

Current Speed

15%	rapid
28%	moderate
41%	slow

16% not perceptible

Most numerous at vegetated sites with thick vegetation and muddy substrates.

S. elodes is virtually identical to *L. arctica*. Until recently *S. elodes* was known as *S.* (or *Lymnaea*) *palustris* (Muller)

Physella jennessi shinneri (Taylor)
Blunt Prairie Physa

Species #1

Distribution Southern Canada, northern United States (south to Utah), Ontario, northwest throughout Manitoba, Saskatchewan and Alberta, north to Great Slave Lake (south of the continuous permafrost line)

Ecology Total of 53 lots

13%	large lakes
4%	small lakes
7%	ponds
3%	rivers 50-100 ft. wide
10%	rivers 25-50 ft. wide
11%	streams 10-25 ft. wide
2%	streams 5-10 ft. wide
2%	marshes
1%	muskeg

Vegetation was usually abundant
moderately abundant - some
sparse - a few

Bottom substrates mud - 50
sand - 2
rock - 1

Current speed slow or not perceptible at all

Most numerous at muddy sites among thick or moderately thick aquatic vegetation. Occurs in lakes, ponds, marshes, and slow moving streams of all widths. Both vernal or perennial habitats. Miller (1966:239) reports that they most commonly live in shallow bodies of water vernal or perennial ponds, sloughs, backwater along streams, especially shallow eutrophic areas in abundant vegetation and a muddy substrate. Depths < 1 m to nearly 5 m.

Fossaria bulimoides morph cockerelli (Pilsbry and Ferriss 1906)
Prairie Pond Snail
-6 + 17 + 3

Distribution Southern Manitoba west to south-eastern British Columbia, north to mid Alberta and south to Vancouver Island.

Ecology Not a large collection, not a lot found. Found in perennial water habitats, such as lakes, slow streams and ponds. Also found in vernal habitats (roadside ditches, temporary pools). Often among dense vegetation with muddy substrates. Pilsbry (1896) refers to their unique ability to survive habitats which are dry throughout most of the year.

Substrate muds or partly muds

Vegetation dense

Currents probably low to not perceptible

Numerous morphs which grade into one another in many intermediates. No geographical trends in their ranges so could call it *Fossaria bulimoides* (Pilsbry and Ferriss 1906) (Lea)

Summary of habitats All three species found demonstrate a preference for habitats with dense vegetation and muddy substrates. Low to no current action and shallow waters. Both *Fossaria* and *Physella* can flourish under vernal conditions.

VITA

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The Canadian Association of
Geographers 1991 Annual
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