UNIVERSITY OF ALBERTA

HOLOCENE TERRACE DEVELOPMENT OF THREEHILLS CREEK, SOUTH-CENTRAL ALBERTA

by

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A Thesis
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in partial fulfilment of the requirements
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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled HOLOCENE TERRACE DEVELOPMENT OF THREEHILLS CREEK, SOUTH-CENTRAL ALBERTA submitted by HENRY A. JACKSON in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE.

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ABSTRACT

Threehills Creek basin in south-central Alberta developed during the Holocene, eroding into glacial and glaciolacustrine sediments deposited mainly during the retreat of the Laurentide ice. The longitudinal profile of the creek exhibits normal development of the upstream portion with a concave-up profile. The downstream portion shows a convex-up profile which is typical of many other creeks of similar size in Alberta.

Four paired terraces developed within the valley, indicating four cycles of incision and aggradation within the system. Mazama ash was discovered in the alluvial sequence of the oldest terrace (T-1) and radiocarbon datable bison bones were discovered in the other three terrace sequences (T-2, T-3 and T-4). The logging of the exposed sections along the creek, along with the radiocarbon dated bison bones that were extracted from these exposures, created a detailed record of the stream's development.

From these alluvial sequences the approximate periods in which the creek finished incising and when lateral accretion started were documented. These transitions were followed by the episodes where vertical accretion became the dominant form of aggradation prior to the next round of incision.

The timing of these geomorphic transitions/episodes is compared against prior studies of postglacial climate change in the southern plains of Alberta and southwest Saskatchewan. Most of the prior records correlate with what was found in the Threehills Creek valley. However, between about 1900 and 1600 yrs B.P., when incision occurred with the Threehills Creek, records do not indicate a significantly wet period as might be expected.

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CHAPTER 1. INTRODUCTION

1.1 Thesis Objective and Background

The major emphasis of this thesis is to interpret the fluvial geomorphology of Threehills Creek during the Holocene. Prior Alberta studies in fluvial geomorphology, and local studies in glacial geomorphology and geology, have helped to develop an integrated evolutionary interpretation of Threehills Creek valley (Figure 1.1).

The study of terrace formation in fluvial geomorphology is still a developing area of research (Slaymaker 1991). A number of theses from the University of Alberta Geography Department have interpreted the Holocene development of small-basin terrace suites. Alluvial terraces in valleys of the Whitemud, Weed, and Strawberry creeks were described by Rains (1969), Shelford (1975), Welch (1983), Rains (1987) and Rains and Welch (1988) respectively (Figure 1.1). These studies complement each other because the creeks all eroded into similar bedrock and pre-Holocene sediments. They are comparable in size, in close proximity to each other, and all drain into the North Saskatchewan River. In Alberta, they reflect a localized record of fluvial erosion and deposition during the Holocene.

The Threehills Creek drainage basin initially redeveloped in a preglacial valley blanketed by glacial and glaciolacustrine sediments left by the retreat of the Late Wisconsin Laurentide ice sheet and proglacial lakes (Shetsen 1987, 1990). Valley evolution has been partly regulated

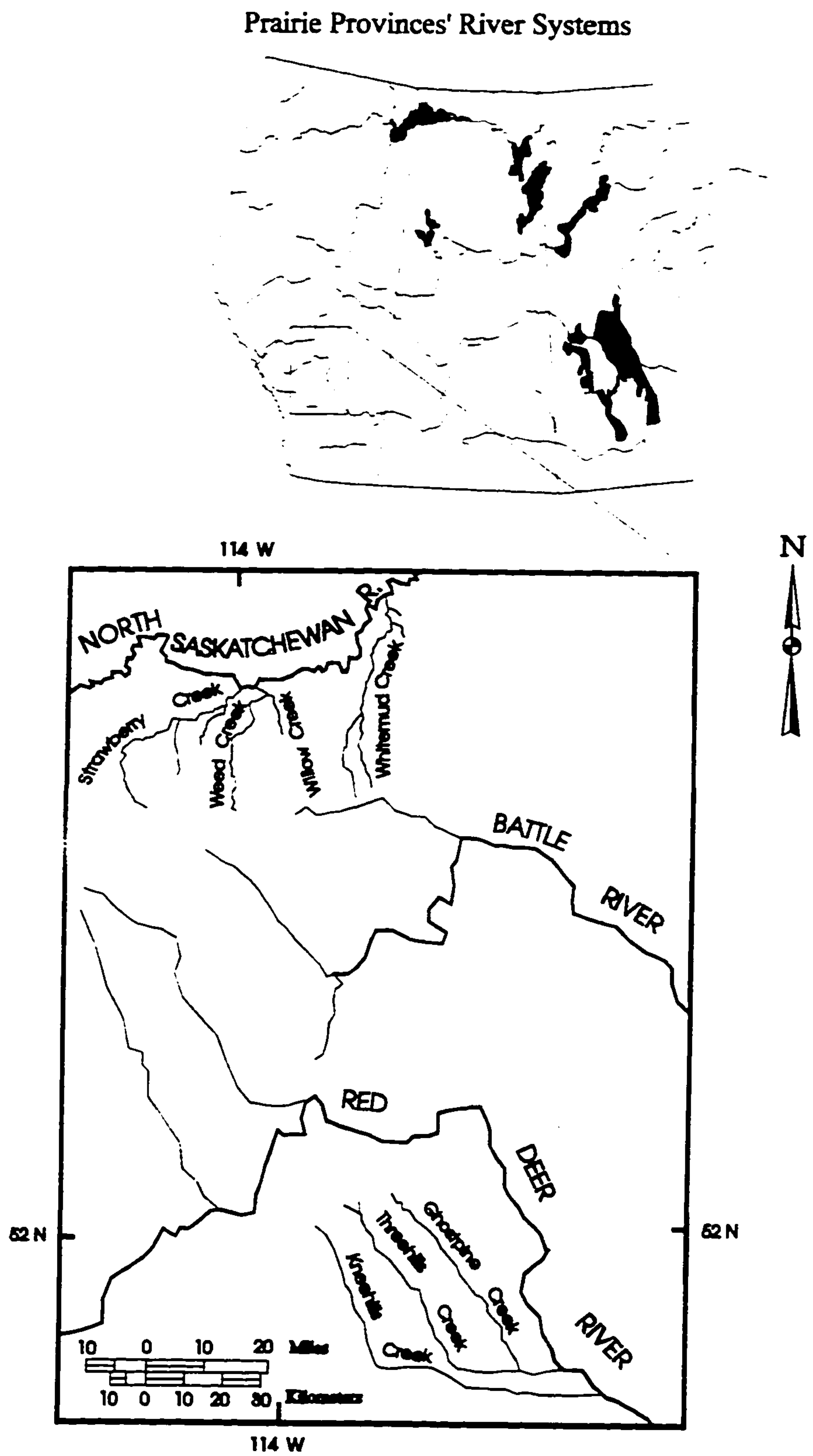


Figure 1.1 Location of study area

by: bedrock control, Glacial Lake Drumheller, later variations of local base-level of the Red Deer River, isostatic rebound, and Holocene bio-climatic variations.

A partial record of the basin's geomorphic evolution is contained in the remnant terraces along the middle to lower reaches of the valley. The alluvial stratigraphy of each remnant terrace gives a sedimentary record of deposition over time. Characteristics of the alluvial sediments reflect basin sediment-inputs and hydraulics, including fluvial sorting. The record of postglacial aggradation and degradation, reflects variation of stream regimen over that time. The terrace alluvium contained bone fragments that were used in radiocarbon dating of the terraces. A Mazama ash marker-bed in the oldest terrace (T-1) sequence helped to confirm the age and correlation of this paired terrace along the creek (Westgate and Dreimanis 1967, Rains and Welch 1988).

The regional geology and pre-Holocene surface deposits are described to better understand the major controls on development. The four terraces of Threehills Creek valley have been mapped and described, and a detailed investigation of the terrace exposures was conducted. The collection of Mazama ash from the oldest sequence, and carbon-datable material from each of the other terrace sequences, has allowed an approximate postglacial chronology to be constructed for the creek.

1.2 Historical Research of the Field Area

Many of the regions of Canada were mapped initially to give general information on the resources that were available to the Government of Canada. This knowledge was then used to draw people to settle and develop Canada's claim on these regions.

In 1857 the British Government sent Captain John Palliser upon a scientific expedition into the region west of Red River to the Rocky Mountains. This initial expedition created a consensus upon the usefulness of the area known as the Palliser Triangle. In 1871, Sandford Fleming directed an expedition for the Canadian Pacific Railway (C.P.R.). The purpose of this expedition was to develop a plan for the C.P.R.'s expansion in the West.

The Geological Survey of Canada (G.S.C.) sent J. B. Tyrrell (1887), G. M. Dawson and R. G. McConnell to map the bedrock and glacial deposits of Western Canada in the late 1880's. Work in southern and central Alberta continued through into the twentieth century for both the Canadian and Provincial Governments. Bretz (1943), Rutherford (1937, 1941), Warren (1937, 1944, 1954) and Bowser, et al. (1951) all worked on this region for the Canadian Government. D. Borneut described the hydrogeology of the Drumheller area in 1969 for the Alberta Research Council. Major contributions to knowledge of the surficial geology of this area were made by C. P. Gravenor and L.A. Bayrock (1956, 1961), and A. MacS. Stalker (1960, 1973).

Stalker (1960) described and mapped an area including the northern section of the Threehills basin. Stalker (1973) dealt with the southern and largest section of the Threehills drainage basin. Shetsen's (1987, 1990) maps integrate available information, with her own interpretations on the Quaternary geology of southern and central Alberta, including the study area.

1.3 Physical Description

The Threehills Creek basin (Figure 1.2) is approximately 442 square miles (1145 square kilometers) in area and is located between 113° W to 113° 45' W and 51° 30' N and 52° 15' N in south-central Alberta. The basin shares the eastern half of the Delburne Uplands (Figure 1.2) (Stalker 1973) with that of Ghostpine Creek basin. The higher Uplands are dominated surficially by draped moraine up to 5 meters thick, with remnants of an esker ridge that measure from 2 to 5 meters high and 8 to 45 meters wide (Stalker 1973). Lower elevations are mantled by glacial lake sediments. The two creeks merge after entering the Red Deer River valley badlands. To the west and along its southern border the Threehills drainage basin is separated from the Kneehills drainage basin by the Kneehills Ridge. This ridge consists of well consolidated, Tertiary, Paskapoo Formation sedimentary rock that partially resisted erosion (Figures 1.2, 3.2). Thicker moraine complexes to the north separate the drainage basin from small, unnamed intermittent creeks flowing north into the Red Deer River (Stalker 1960).

The Delburne Uplands represent a preglacial divide separating the ancestral Bow and Red Deer rivers. The Delburne Uplands cover a large area and with their gentle slopes the hills appear less striking than the Kneehills, Threehills and Lumina hills of the region (Stalker 1973).

1.4 Methods of Study

Initial field reconnaissance of the valley started in the summer of 1992. Terraces were mapped on laser copies of aerial photographs and alluvial stratigraphies of the exposed sections were recorded and correlated to the mapped terraces.

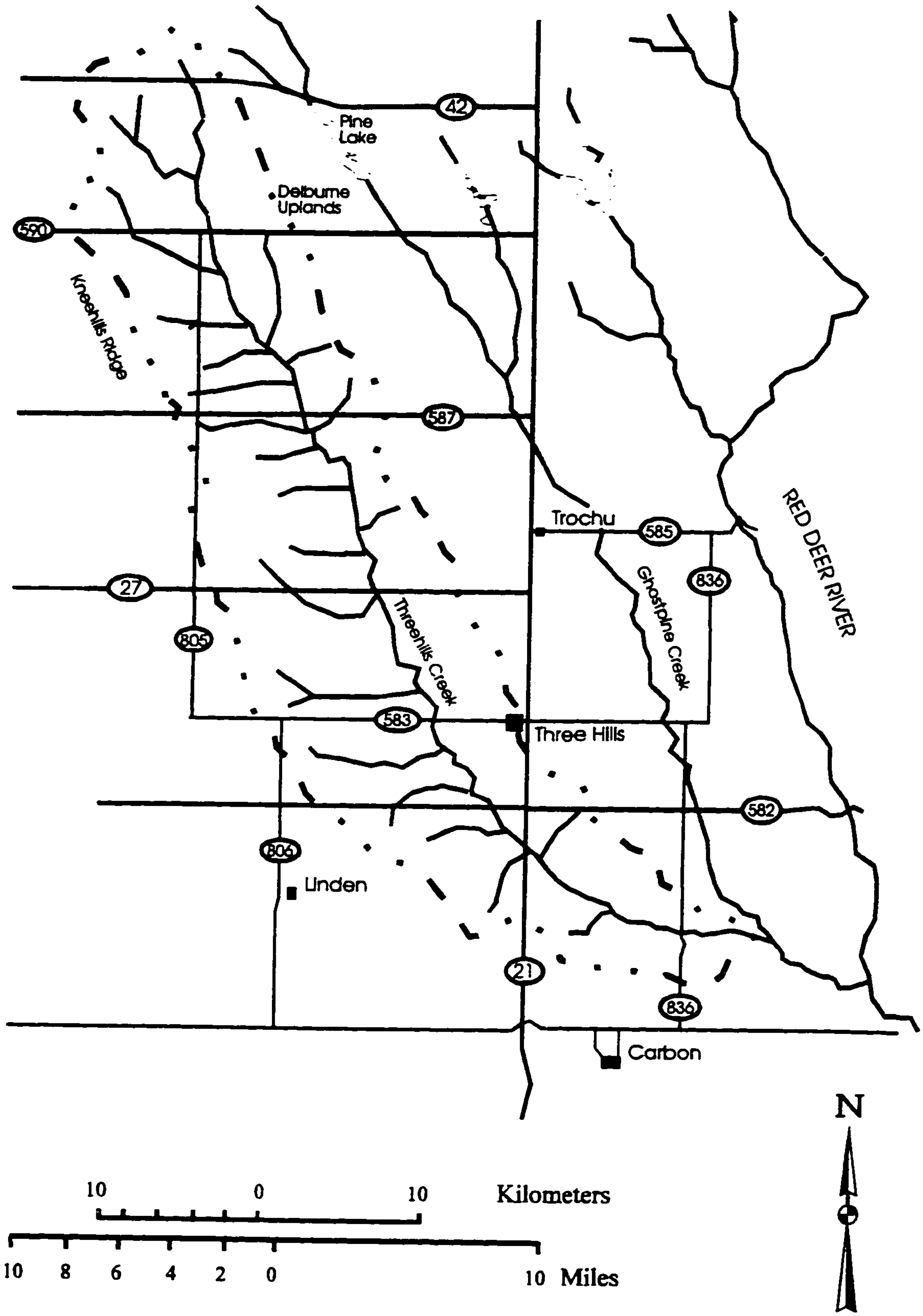
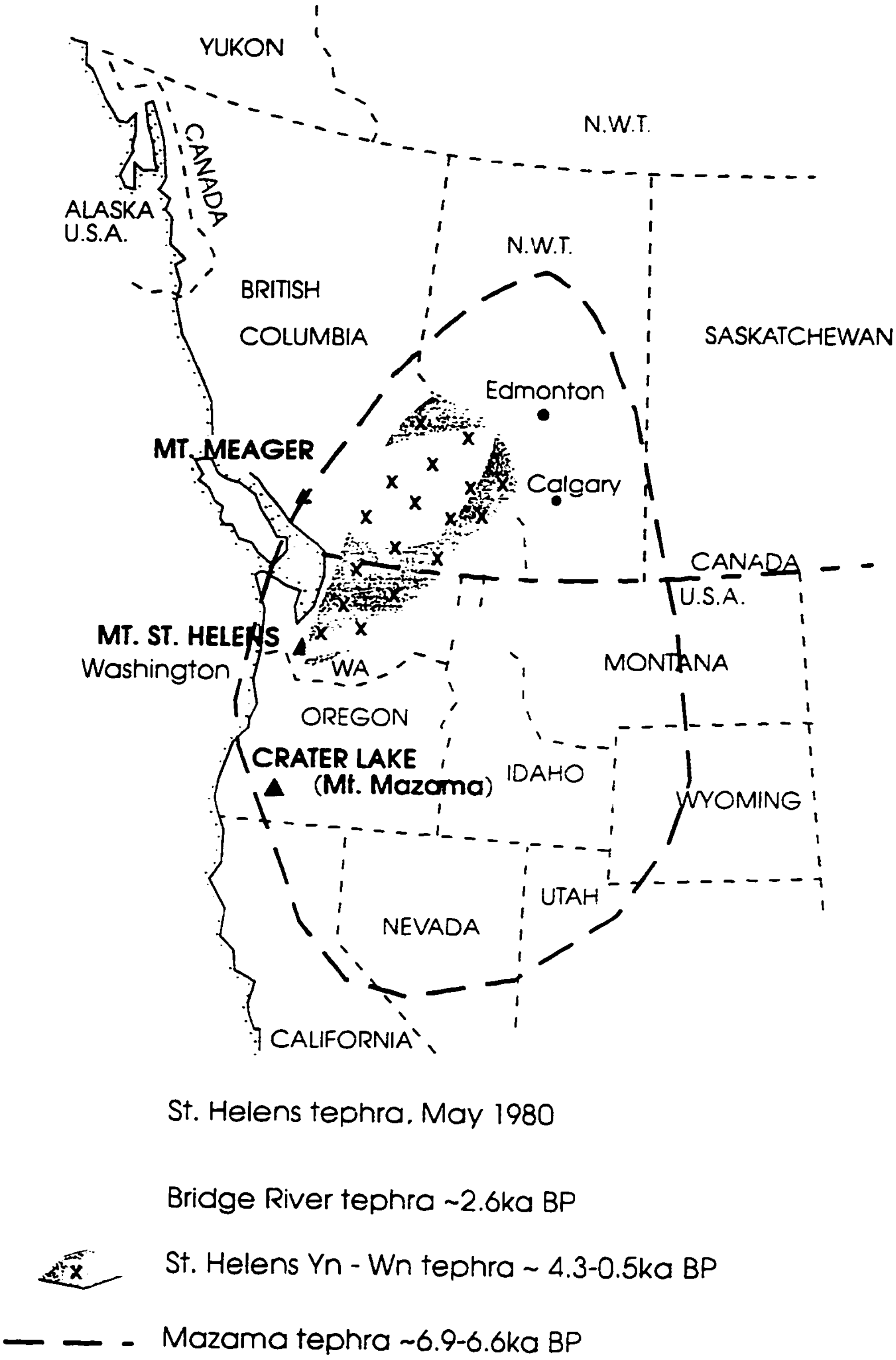


Figure 1.2 Threehills Creek and basin

The stratigraphic sections that were investigated and interpreted were all created as a direct result of fluvial action. Each section tells a different story with reference to the whole creek's history. The sedimentary sequences were generalized, from the bedrock up, as (1) lag gravels armouring the previous creek beds (2) point bar deposits in the form of pebbles, sands, silts to minor clays and (3) overbank fines. Lag gravels were predominantly that of local bedrock (Paskapoo Formation sandstone and Horseshoe Canyon Formation sandstone and shales) with lesser amounts of reworked Canadian Shield granites.

The general criteria for identification of point bar deposits in the sedimentary sequence were apparent sediment sorting, grain size and stratification. Commonly recognized were sand lenses, and the fining upwards of grain size starting with a small layer of alluvial gravels, through sands to silts and clays. Cross bedding and cross lamination reflected point bar deposition, whole overbank fines were primarily horizontally stacked units of well-sorted sediments but with little current-bedding. Poorly developed, organic-rich bands of former incipient soils on the floodplain surfaces were commonly observed between overbank flood sediment units.

Mt. St. Helens and Mt. Rainier, Washington; Mt. Meager, British Columbia and Crater Lake, Oregon, are all composite volcanoes in the Cascade Mountains of western North America (Figure 1.3). These composite volcanoes act as release valves for the igneous pressure beneath them, episodically erupting. Present day Crater Lake, Oregon, was the site of a massive volcanic explosion about 6,600-6,800 yrs B.P. (Smith and Westgate 1969, Westgate 1977). Tephra from this site is referred to as



Source: Westgate and Briggs 1980

Figure 1.3 Distribution of prevalent tephras to be found across north west North America.

Mazama ash and was spread over large portions of western Canada and northwest U.S.A. (Figure 1.3).

The mineral composition of tephra of each eruption is theoretically unique. The use of signature minerals (Table 4.1 and Figure 4.26) within a tephra sample allows for the differentiation between eruptions from the same region. This signature has been used in the past to discern between; Mazama, St. Helens, Bridge River, Glacier Peak, Pearlette and Bishop tephras/tuff (Smith and Westgate 1969, Westgate and Briggs 1980). With the positive identification of these marker beds and determination of their ages, it is possible to use them for dating the stratigraphic sequence in which they occur.

Because tephra is fine-grained, widespread distribution and redistribution of the sediment is quite likely. A significant layer of tephra must be preserved quickly upon settling for it to be identified and useful as a stratigraphic marker. Capture of tephra in a well placed terrace, that is somewhat sheltered from prevailing winds, may allow more time for overbank deposition to bury it. With a known location of tephra in a terrace, it is possible to extrapolate the age of other terraces of similar height within the system without the marker being present in all of the terraces.

Numerous bones trapped in alluvial sediment were collected at exposure sites and radiocarbon dated by Alberta Environment. A sample of Mazama ash was identified by electron microprobe analysis, Department of Earth and Atmospheric Sciences, University of Alberta.

Digital Elevation Models (DEM's) were used in the construction of the longitudinal profile. The DEM's were created by the Government of Alberta from aerial photographs and have a resolution of 25 sq. meters per pixel. Each DEM arrived with UTM coordinates of eastings and northings for reference of the start of each file. Each file is broken into x, y and z columns with the x referring to the eastings, y referring to the northings and z to the elevation of that particuluar coordinate.

The software package "Terra Firma" created by Dr. R. Eyton, formerly of the Department of Geography, University of Alberta, was used to determine spot elevations at every bend in the creek and these were recorded in a spreadsheet. Additionally, the northings and eastings of these spot elevations were recorded and the distances between the locations were calculated. The spreadsheet was then used to prepare a chart, creating the longitudinal profile. The terrace heights were recorded in this manner and then placed upon a chart to compare the creek level elevations and terrace elevations to the locations. The cross-sectional profiles were created using the same technique.

Accuracy of vertical elevation in photogrammetrically produced DEM's is such that 90% of the vertical measurements will have errors less than 3 m, relative to the stereo model datum (Land Information Services Division 1988). Spot readings with an altimeter were used to compare and confirm the accuracy of the above method. The altimeter had 2 m gradations but with interpolation gives greater apparent accuracy in confirming the elevations recorded from the DEM's.

CHAPTER 2. SELECTED RIVERS AND CREEKS OF ALBERTA

2.1 Introduction

The Milk River starts south of the Canadian border in Montana. heads north into southwest Alberta and follows eastward along the Canadian/American border to southeast Alberta (Figure 2.1). The Milk River then crosses the international border joining the Missouri-Mississippi which drains into the Gulf of Mexico. In northern Alberta. the Athabasca and Peace rivers drain north into the Slave River through the Northwest Territories into the Arctic Ocean.

The Rocky Mountains Great Divide serves southern Alberta as its western border with British Columbia and marks the western boundary of the Hudson Bay drainage. The majority of central and southern Alberta is drained by the Saskatchewan River systems. The Red Deer River. a major contributor to the South Saskatchewan. rises in the Rocky Mountains west and south of the City of Red Deer, west of the Town of Sundre. It drains north east through the City of Red Deer, then flows east. turning south 90 km north of the City of Drumheller. The Red Deer River passes through Drumheller and then flows east. joining the South Saskatchewan River just east of the Saskatchewan/Alberta border. near the Town of Empress (Figure 2.1). The North and South Saskatchewan rivers then join east of Prince Albert. Saskatchewan.

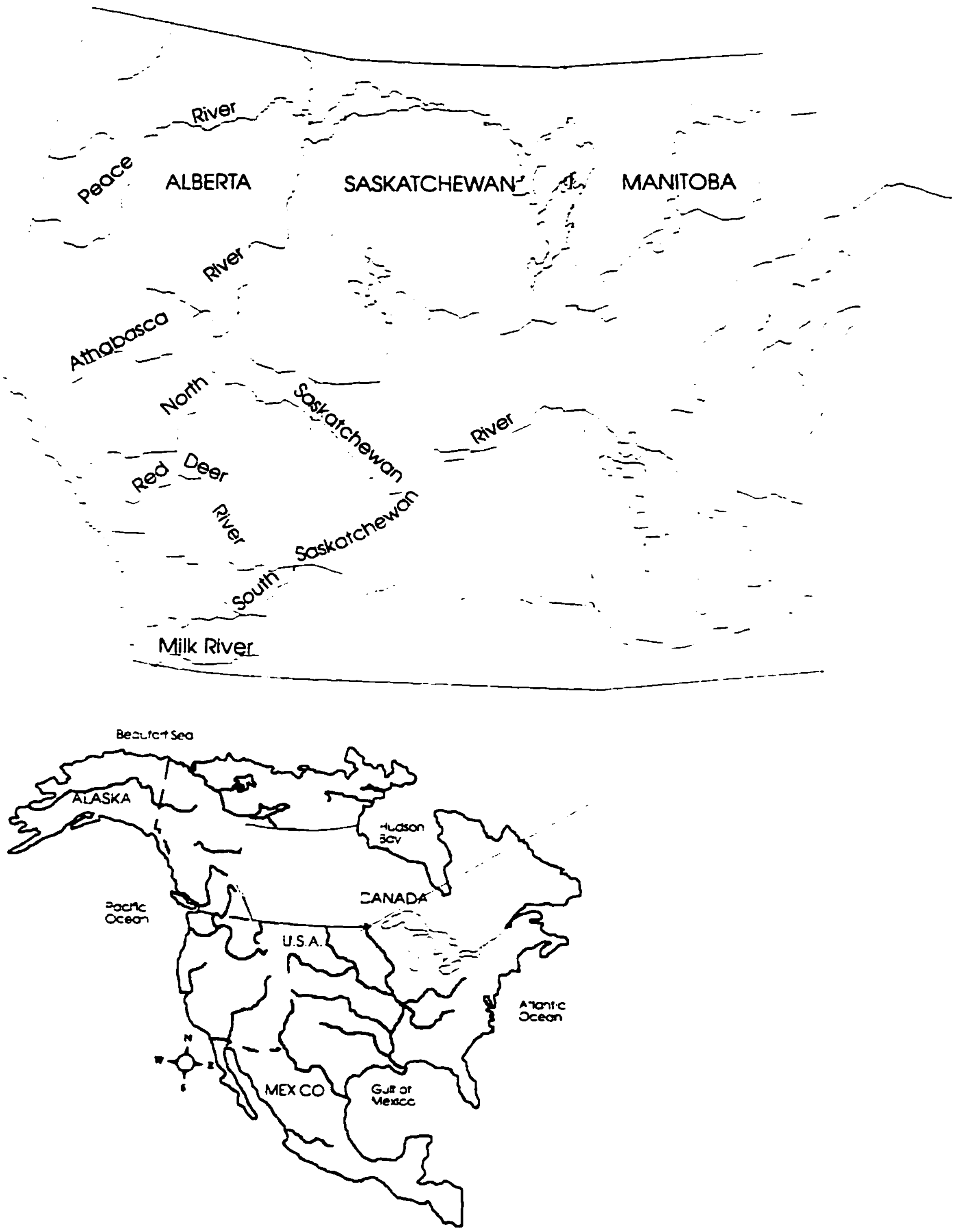


Figure 2.1 Saskatchewan basin in context of the American drainage

2.2. Controls

There are some basic factors of control that determine how a river system will evolve: (1) base-level, (2) sediment-sources. (3) climate change and (4) tectonics (Schumm 1993). These factors are complex in their interaction and their effects can easily overlap and be misinterpreted. For separation of these factors, the geomorphology of the region must be studied in detail to minimize misinterpretation.

Base-level is the theoretical level to which a river can erode its valley bed. Sea-level is considered the ultimate base-level. However, sea-level has little relevance to studies of prairie creeks; it is the rivers that they drain into that function as their base-level (Rains 1969, Shelford 1975, Welch 1983, Rains and Welch 1988). For the Threehills creek study, the local base-level is the Red Deer River.

It is recognized that base-level both affects a river and is affected by that same river. If the base-level moves up vertically, the river would aggrade; base-level moving down vertically would cause the river to degrade. Even a change in channel pattern, such as a cut off in the stream, changes the dynamics of a river, creating local steepening and upstream channel degradation and downstream aggradation (Winkley 1976, Schumm 1993). The river responds to the changes and adjusts to maintain an equilibrium. In the case of the cutoff example, the river responds by changing the channel pattern, width and depth. However, should the magnitude of change be large, incision results, with the whole channel being affected (Schumm 1993).

A channel also responds to the rate of change. A slow rate of change encourages the stream to move laterally, thus changing the pattern of the stream and incision is hardly noticeable. A faster rate of change will cause the stream to incise into its own channel bed (Yoxall 1969).

The duration of change is a combination of both rate and magnitude of change. Over a long period of time with a small magnitude of change the stream's response would be pattern modification and may even appear non-erosive. However, change over a short duration, where the magnitude is large, creates incision and this incision can move upstream affecting the longitudinal profile long after the base-level lowering has occurred (Schumm 1968, Schumm 1993).

The geologic controls of a basin can be mapped and are generally more passive than either the base-level or geomorphic controls. It is the relief, areal and linear factors (Schumm 1956 from Ritter 1986) that determine the size and shape of the basin, and thus the nature of the channels by which the basin is drained. This does not preclude an earthquake or fault changing the basin dramatically over a short period of time but even this effect would be recorded in the fluvial sediments.

Bedrock controls such as lithology and resistance to erosion are reflected in how fast a stream responds to changes in base level. A change in bedrock lithology can create a knickpoint in the longitudinal profile that will slowly travel upstream over time as it incises into the bedrock.

Sediment and its cohesiveness can also be reflected in the profile. Should the valley alluvium be consistently resistant due to sediment size, lithology or vegetative control, a knickpoint can travel a long distance up stream. However, should the alluvium be easily eroded, the response of the stream can be spread along the channel in a short period of time. This response controlled by the alluvium would not produce measurable stream incision in the profile (Schumm 1993).

Geomorphic controls such as slope are important because they increase or decrease stream energy. Slope change results in a stream either aggrading or degrading at the point of change. In a longitudinal profile, degradation is represented by a knickpoint which travels upstream as a response. Aggradation produces a levelling of the longitudinal profile.

Channel confinement by valley walls has an important impact on whether a stream will incise or meander. If the stream is in a wide valley, its response to base level change will be to meander and absorb the change by spreading laterally. When confined by steep valley walls the stream will either aggrade or degrade. Structural controls such as a fault line can confine migration in a lateral shift and can also be reflected in the creek's profile.

The whole morphology of the system is important as the shape of the system will dictate how the stream can respond. If the stream is winding, the stream response to a base level drop could be to become more sinuous rather than degrading. However, if the stream is braided, base level drop would create stream incision (Schumm 1993).

Climate plays an important role in the development of all river systems. It is the mechanism that delivers the erosive element, water, to the basin and affects the type of vegetation that will grow and develop in and along the valley walls and the rest of the basin.

Stream response during and after a rainfall reflects soil structure, slope and vegetation within the basin. These factors determine the infiltration of rain water and its delivery to the streams. The regimen of the stream would also be affected by seasonal variations delivering precipitation to the system in the form of either water or snow and the timing and duration of the snow melt. The speed, quantity and location of localized downpours can also create pulses of sediment and water discharge within the basin.

Seasonal differences of temperature with hot summers and cold winters have huge impacts upon the system. In more extreme latitudes, these seasonal changes mechanically loosen sediments that influence the sediment load of the river system (Schumm 1968, Schumm 1993).

Changes in climate and their effect on sediment loss within a system have been studied in the past (Langbein and Schumm 1958, Schumm 1993). A movement from humid to subhumid or superhumid climates involves no significant change in volume of sediment delivery within the system. However, change from a humid to a semiarid environment initially increases the sediment load significantly with a leveling off over time that is still higher than within a humid environment. With a switch from humid to arid climate, there is a significant slow-down of sediment delivery within the system. Arid environments result in the slowest rates of sediment movement out of a basin (Langbein and Schumm 1958).

Tectonics have a significant impact on many systems. When base level of a stream lowers, the initial effect is upon the channel. First, the incising channel affects the valley walls and then the rest of the system. The stream response is a short-term pulse of sediment delivered through the system with the knickpoint being measurable in the longitudinal profile (Gardner 1983). Uplift in the upstream portion of a system affects all the upstream portion of the basin with an increase of slope and creates a much larger pulse of sediment over a longer period of time (Schumm 1963).

2.3 Alberta Drainage Pattern

The Laramide orogeny of the Rocky Mountains created the bedrock controls of the Saskatchewan River systems and their drainage into Hudson Bay (Figures 1.1, 2.1). During the late Pleistocene both regions were drained through a series of proglacial lakes, as the Laurentide ice retreated (St. Onge, 1972). Terrace development of the Red Deer River valley has not been studied for specific details. Therefore, the North Saskatchewan River's evolution will be assumed to parallel that of the Red Deer River.

2.3.1 North Saskatchewan River

For the North Saskatchewan River (Figure 2.1), Westgate (1969) documented four terrace treads in the valley close to Edmonton. He documented the treads as T-1 for the oldest and highest in elevation to T-4 for the youngest, which is also the modern floodplain (Table 2.1). Ages of the terraces were defined using radiocarbon dating and the Mazama ash bed marker.

Welch (1983) summed up previous evidence and proposed the development of the North Saskatchewan River in five stages to create the present river valley. Figure 2.2 depicts the stratigraphic cross-section to be discussed. Stage 1 is the progressive deglaciation of the area.

At Stage 2 the valley had initially incised 6-9 metres below the prairie surface, followed by a rapid aggradation of T-1 sediments at about 10.740 $\pm$ 470 yrs. B.P. (Rains and Welch 1988). This stage related to further deglaciation to the east of Edmonton as the level of Glacial Lake Edmonton dropped. The sediments forming these terraces are interpreted as braided channel deposits.

Table 2.1: Terrace development of North Saskatchewan River

Terrace Designations Used in This Study	Approximate Terrace Tread Elevations above Present Low Water Surface (Modified after Westgate. 1969)	Approximate Dates (years B.P.) based on carbon dated material and tephra markers (Rains and Welch 1988)
T-1	45 m (Approx. 150 ft.)	11,345 ± 420 10,740 ± 470
T-2	30 m (Approx. 110 ft.)	9-10,000
T-3	19 m (Approx. 60-70 ft.)	8-9,000
T-4	9 m (Approx. 20-30 ft.)	>8000

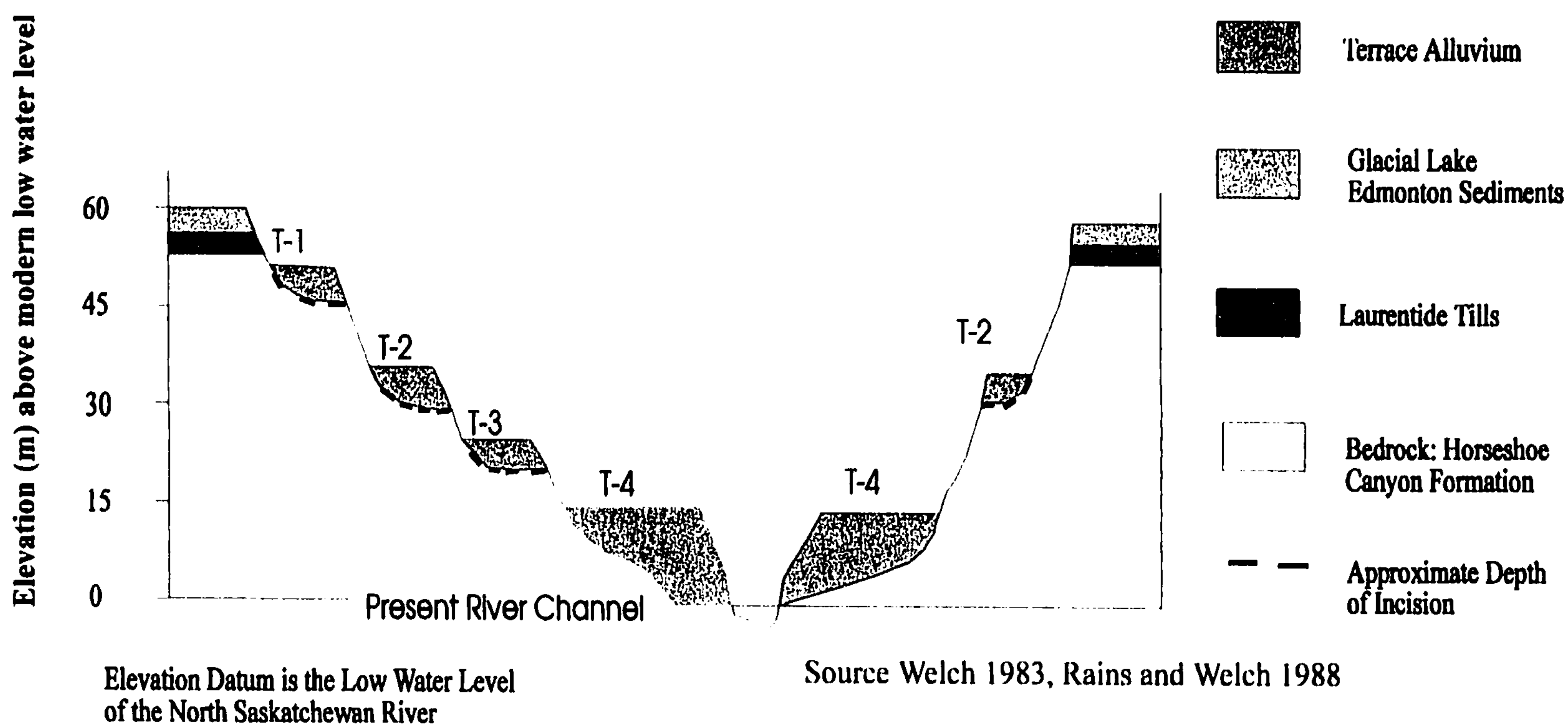


Figure 2.2 Proposed stages of North Saskatchewan River valley evolution, Edmonton

Drainage of Glacial Lake Bruderheim between 9-10,000 yrs B.P., (Bayrock and Hughes 1962; St. Onge 1972, Welch 1983) was cited as the cause of 15 m of incision by the North Saskatchewan River. By then the Laurentide ice front was in northern Saskatchewan at the Cree Lake Moraine (personal comment, Shaw 1997). Glacial Lake Saskatchewan formed the new base level.

Rapid incision of 11 m into T-2 alluvium resulted from the progressive recession of the Laurentide ice sheet to the north-northeast (Welch 1983). Increased deposition by lateral accretion then marked a period of valley widening without appreciable incision. The resulting T-3 alluvium consists of basal gravels, point bar and overbank fines indicating increasing stability in the system. This period of stability most likely occurred from 8-9000 yrs B.P. The two datable objects found in the T-3 appear anomalous. The first, a bone found in alluvium, is dated at 10,700 ± 150 yrs B.P. and could easily have been reworked from T-1 deposits. The second, dated at 2090 ± 110 yrs B.P., was found in a paleosol above the alluvium. The base limit for the period of aggradation within the T-3 segments of the North Saskatchewan River, was defined by the numerous, less anomalous dates found in T-4 (Rains and Welch 1988).

Starting before 8,000 B.P., the latest stage (5) was of slow incision into T-3. The following planation and lateral accretion were slow with incorporation of radiocarbon datable material and Mazama ash in T-4 alluvium pinpointing this terrace development. Modern flooding can still partly cover T-4, as during the 1915 and 1986 events. This indicates a stable profile with relatively slow incision at present.

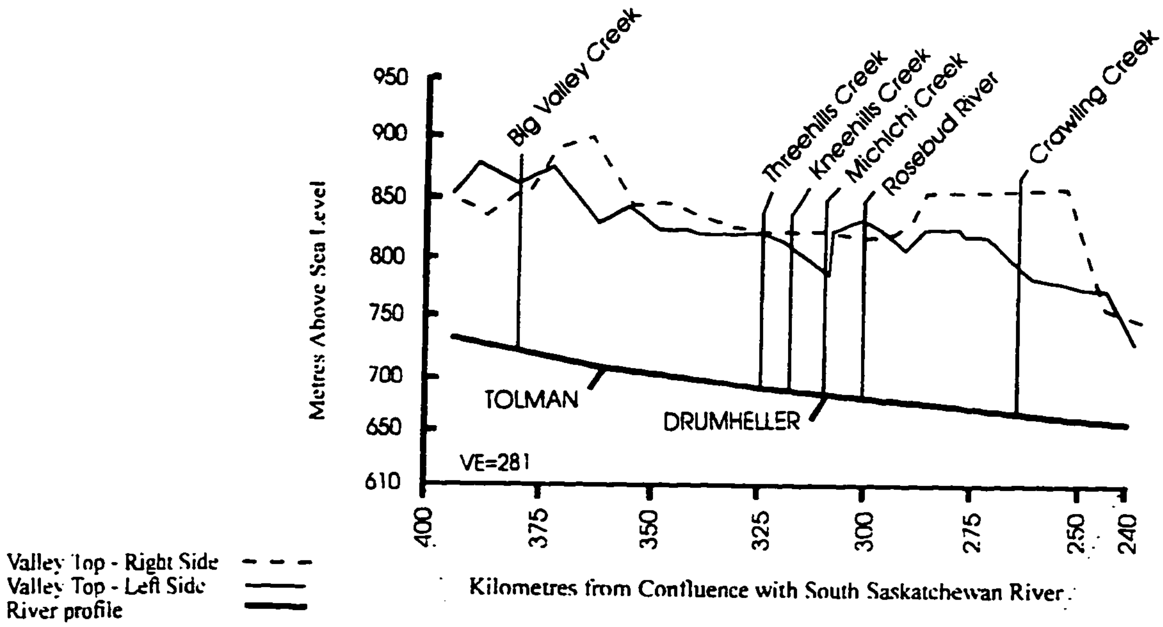
2.3.2 Red Deer River

Prior to the arrival of Laurentide ice, the Red Deer River Valley was shallow, following a route to the north and east through to the current Battle River Valley. Laurentide ice filled the shallow valley and effectively blocked any drainage through the preglacial river valley during deglaciation.

Deglaciation had an immense effect upon the Red Deer River Valley from the Delburne uplands to north and east of Drumheller (Figure 3.2). In the time period in which Glacial Lake Beiseker developed and started draining to the south, the upper part of the Red Deer River drained through the Innisfail Spillways. As more land was exposed, the river developed a new easterly route immediately north of the Delburne Uplands. This new channel carried both land surface runoff and glacial melt water. To the north and east of Delburne, the current Red Deer River makes a right angle bend, heading south through approximately 23 km (15 miles) of varying topography that obviously played little part in determining this path (Stalker 1973) (Figure 1.1).

The path of the valley was formed at the border between active Laurentide ice to the east and stagnant ice to the west. The thin ice over this ridge was more susceptible to melting and would have been the path of least resistance. Though the river significantly dissects the varying topography of the Delburne uplands and the ridge east of Trochu, its slope is only 0.5 m to the km (Figures 2.3.a, 2.3.b). Upon reaching the buried Kneehills Valley, the Red Deer River changed course east for 9 km (6 miles), then followed the preglacial Bow River valley between the Hand Hills and Wintering Hills. As more active ice blocked the drainage to the east, spillways formed

Figure 2.3.b Sub Section of Red Deer River Profile and Confluence of Tributary Creeks



Modified from R. Kellerhals,
C.R. Neill and E.I.Bray 1972

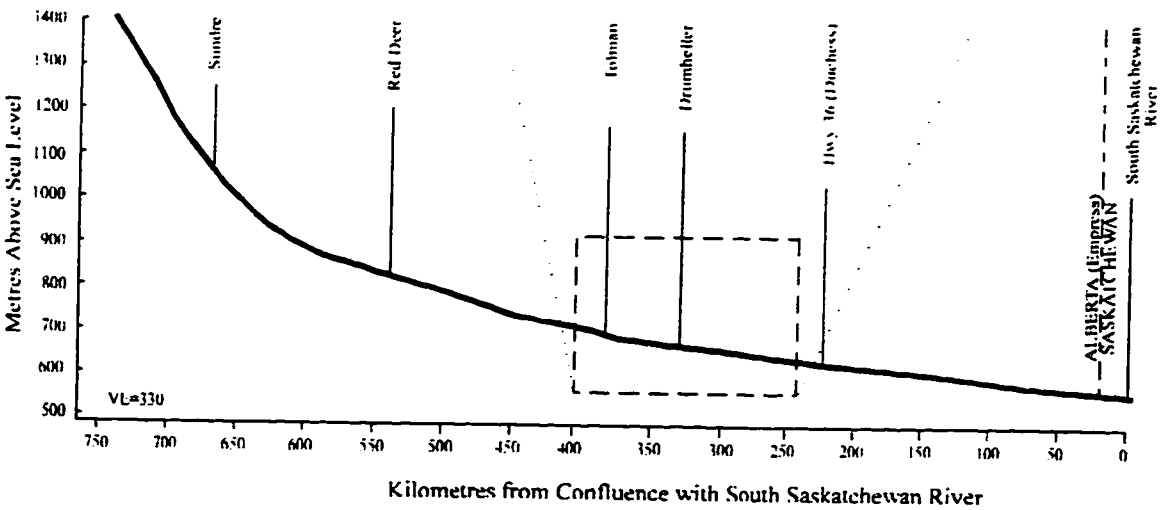


Figure 2.3.a Profile of Red Deer River to Confluence with South Saskatchewan River

west of Crawling Valley, Crawling Valley itself, and Gem Spillway (Stalker, 1973). These episodic base-lowering events along the Red Deer River valley created the initial incision and development of the Red Deer River valley longitudinal profile and terraces.

2.3.3 Joffre Bridge Terrace

Located by the Red Deer River near the town of Joffre, the site can be found 300 m upstream from the Joffre Bridge, which crosses the Red Deer River east of the City of Red Deer. This lowest terrace remnant has a 5 m exposure of alluvium that overlies sandstone bedrock. This section consists of 2.38 m of an upward fining sequence of massive sandy silt, and this is capped with a buried paleosol. A 0.34-0.44 m thick bed of Mazama ash covers the paleosol and is buried by poorly bedded silt with multiple organic horizons (Waters 1979, Waters and Rutter 1984).

2.4 Alberta Creeks: Chronology of Valley Development

2.4.1 Introduction

The cut and fill development of creeks in Alberta is mechanically similar to that of the North Saskatchewan River, with creek incision into glacial lake sediments, then glacial debris and finally into the bedrock. The terraces found in the valley system are then a reflection of the controls of the creek during the Holocene. Their chronology is presented to give a generalized perception of the cut and fill that took place.

Planimetric distributions of terraces along a creek system are indicative of its chronological development. The floodplain is the area which is covered by the stream when an increase in the volume of water in the stream can no longer be contained by the regular channel. During floods large amounts of sediment are carried in the stream. When this flood water is isolated on the floodplain it is slowed and sediment settles. Depending upon the amount of sediment in the floodwaters and duration of this overbank episode, thick layers of sediment may be added to the floodplain increasing its elevation above the channel. Floods have continued to add to the floodplain of the North Saskatchewan River valley, Edmonton, even as recently as July 1986, (Mustapha et al. 1981, Rains and Welch 1988).

A geomorphic threshold is when an input into a basin such as a climate change in the form of either a wetter or drier regimen, sediment biuld up, or a change in base level. A combination of these and other factors can create what is refferred to as a geomorphic treshhold. When a geomorphic threshold is reached, a stream can initially respond by incising (Schumm 1993). Depending upon the rate of migration before the stream again reaches a period of stability much of the evidence of the previous floodplain can be destroyed. When the stream stabilizes aggradation occurs and alluvial buildup in a new floodplain occurs. Terrace remnants that are left reflect the longitudinal profile of the last period of aggradation and the new longitudinal profile of the current stream.

Finding paired terraces of similar age and height on each side of a stream is rare. Lateral movement usually erodes one or the other (or more often both terraces) over time. It is for this reason that terrace remnant elevations are plotted over a longitudinal profile so that a pattern of inferred paired terraces can be constructed from the remnants. When the terrace remnants are graphed it becomes obvious that not all the terraces are paired. Some remnants can be found in between the profiles of two previous terraces sequences and would be referred to as unpaired terraces.

Determining the distribution of the older terraces in a valley is limited due to the lateral migration of the creek erosion destroying both the terraces and any evidence that they contain to date them (Rains 1969. Shelford 1975, Welch 1983, Rains and Welch 1988). In a planimetric distribution the system shows extensive modern floodplains (i.e. youngest terrace sequence) being developed alongside of the creek path. Each successive terrace sequence is found grouped at a higher elevation level and in decreasing numbers when compared to the prior terrace sequence.

2.4.2 Whitemud, Weed and Strawberry Creeks

As stated in the introduction. the Whitemud. Weed and Strawberry creeks (Figure 1.1) were described by Rains (1969), Shelford. (1975) and Welch (1983) respectively. Their similarity of size. lithology. relief. location and direction of drainage lead Rains and Welch (1988) to do a comparative analysis. This helped to define the controls that created similar morphological patterns. Similar age and relative depth of incision of the terraces between the creeks (Table 2.2) indicate that their development responded to controls (Welch 1983). This further stimulated a preliminary investigation of Ghostpine Creek (Rains et al. 1994) when carbon-datable material was discovered in 1986.

The chronology of terrace development for these three creeks is based on the Mazama ash marker found in Strawberry Creek T-1 alluvium and radiocarbon dates on bone, shell, wood and charcoal within the T-1 to T-4 terraces. Whitemud and Weed Creek terraces also yielded dates in the terrace alluvium.

The development of the creek system shows initially, creek incision was into glacially derived sediment and then into easily erodible

Table 2.2 Comparison of the Strawberry, Whitemud and Weed creeks terrace terminology and heights*

Strawberry Creek (Welch, 1983)	Whitemud Creek (Rains, 1969a)	Weed Creek (Shelford, 1975)
Terrace Height Age	Terrace Height Age	Terrace Height Age
T-1 20-22 m 8700-6000	High-level 15 m 8195	Highest 20-22 m NA
T-2 12-14.5m 4685	Upper 12 m 5490-4225	Upper 13-16 m NA
T-3 6-8 m 1625-760	Middle 4.5 m 3255-2940	Middle 9-11 m 2765
T-4 3-4.5 m 1965	Lowest 3 m 1220-315	Lowest 3-6 m NA

*Height range above present low water surface.

NA Not Available

Source: (Rains 1969, Shelford 1975, Welch 1983, Rains and Welch 1988) sedimentary rock. The last major tectonic activity in this area was most likely isostatic glacial rebound. It is not easily measurable and its importance in creek development is uncertain. The longitudinal profiles of Alberta creeks with their dated, projected terrace profiles compare favorably with climatic fluctuations. This indicates that climate control was probably the most important factor in their development.

Phase 1 development of T-1 terraces on the three creeks started after the last glacial lake in the area drained (Welch 1983). Incision continued from the time of glacial lake drainage until approximately 8500 yrs B.P. The oldest recorded dates along the Strawberry Creek were found in a section containing Mazama ash and a buried paleosol containing datable charcoal. The height between the contact of alluvial gravel/bedrock and the buried paleosol is 2.5 m. Above the paleosol was 9 cm of silt and fine sand with a band of 6 cm of Mazama ash and 30 cm of overbank fines covered by colluvium (Welch 1983, Rains and Welch 1988). The buried charcoal was dated at 8600 $\pm$ 125 yrs. B.P. and the ash is known to be dated at 6600 yrs. B.P. (Welch 1983, Rains and Welch 1988).

In situ bi-valve mollusc shells found in the basal gravels of another section along Strawberry Creek were dated at 8015 $\pm$ 135 yrs B.P. (Welch 1983, Rains and Welch 1988). A further bone (mandible from a wolf) found at the terrace tread of the T-1 was no longer in situ but was dated at 5640 $\pm$ 310 yrs B.P. Though not properly positioned within the section, the bone is of a similar age to the terrace (Welch 1983, Rains and Welch 1988).

A juvenile bison bone dated at 5865 $\pm$ 135 yrs B.P. was found at the contact between alluvial and colluvial material on another T-1 section along Strawberry Creek (Rains and Welch 1988). The combination of the two distinct dates of in situ material and the Mazama ash, leads to the assumption that the creek was aggrading from prior to 8700 till about 6000 yrs B.P. (Rains and Welch 1988).

A piece of bison pelvis, dated 8195 ± 1090 yrs B.P. was found on a tread of a T-2 section of Whitemud Creek. Although not in situ, with the knowledge of the other two in situ dates, it can be presumed to be representative of aggradation of the T-1 of Whitemud Creek (Rains and Welch 1988).

Incision into T-1 alluvium started around the 5600 to 5000 yrs. B.P. period and continued for up to a thousand years. A bone fragment found in Strawberry Creek T-2 alluvium was dated at 4685 ± 260 yrs B.P. A similar date of 4225 ± 150 yrs. B.P. comes from Whitemud Creek T-2 alluvium (Rains 1969, Rains and Welch 1988). Also, along the downstream reaches of the Whitemud, mollusc shells found in situ, in terrace alluvium presumed to be of T-2 origin, were dated at 4220 ± 250 yrs B.P. (Rains and Welch 1988).

Anomalous findings and dates also appear along T-2 sections of Strawberry and Weed creeks. Along Strawberry Creek a bison skull found buried by 55 cm of overbank fines on a T-2 section was dated at 1135 ± 80 yrs B.P. Given the religious significance of a bison skull to the First Nations people of the prairies it has been suggested that this skull may have been buried during a religious ceremony. In a downstream section of Weed Creek, close to its intersection with the North Saskatchewan River, charcoal buried 65 cm beneath the surface by a sandy loam was dated at 1075 ± 80 yrs B.P. (Sharma 1973). The proximity to the intersection and the young date of the charcoal suggests that a high-magnitude flood of the North Saskatchewan River most likely buried the charcoal.

Relevant non-anomalous dates for T-2 sediments indicate incision into T-1 sediment was from about ~5600 to ~5000 yrs B.P. From the datable materials found in T-2 alluvium the period of aggradation of T-2 would have been between approximately 5000 to 4000 yrs B.P. (Rains and Welch 1988).

A major find in T-3 alluvium of a relict beaver dam in Whitemud Creek contained wood that was dated at 3180 $\pm$ 85 yrs. B.P. The dam served as a catchment for dismembered bones and two bison bones dated at 3200 $\pm$ 80 yrs B.P. and 3255 $\pm$ 90 yrs B.P. were found in the beaver dam. Three other samples of datable material were found along the valley and revealed dates of 3220 $\pm$ 125 yrs B.P., 2940 $\pm$ 125 yrs B.P. and 2025 $\pm$ 205 yrs B.P. The nature of the evidence indicates that the channel was stable from approximately 3200 to 2800 yrs B.P. (Rains 1969, Rains 1987, Rains and Welch 1988).

At Weed Creek, bison bone found and dated at 2765 $\pm$ 90 yrs B.P. was recorded by Shelford (1975) as coming from T-4. Rains and Welch (1988) reassessed the terrace data and contemplated the more likely possibility of it being, if not a T-3, an intermediate terrace between a T-4 and T-3 .

Two bison bones were found at two different sections of T-3 alluvium of Strawberry Creek. The oldest, a bison skull 1625 $\pm$ 80 yrs B.P., was recovered from lag gravels 20 cm above the base of the section (Rains and Welch 1988). The second, a bison vertebra 760 $\pm$ 85 yrs B.P., was found in point-bar sands. Both appear non-synchronous with the known dates of Whitemud Creek but no known cause or explanation for either their dates or locations can be made (Rains and Welch 1988).

Current T-4 alluvium would be considered modern with overbank fines still creating the floodplain. A bison bone sample dated at 1965 ± 75 yrs B.P. was found in overbank fines on a T-4 section of Strawberry Creek. Four datable specimens were found along three sections of the Whitemud Creek. The three oldest are bison bones, the fourth wood. A bison scapula found in overbank fines was dated at 1220 ± 70 yrs B.P. (Rains and Welch 1988). Two bison bones were found in the same section; the bone closest to the basal contact was dated at 705 ± 70 B.P. the other, stratigraphically higher at 810 ± B.P. A much younger buried tree trunk buried in overbank fines was dated at 315 ± 70 yrs B.P. showing this period to be again more stable (Rains 1969, Rains and Welch 1988).

Rains and Welch (1982) interpreted the development of these creeks by looking at the morphology, distribution, stratigraphy and chronology of remnant alluvial terraces. They noted that each creek had a suite of four, paired terraces. The longitudinal profiles of the creeks are composite with concave-convex segments. Alluvium within the terraces reflects lateral and vertical accretion over relatively lengthy episodes, separated by shorter phases of incision.

2.4.3 Ghostpine Creek

Ghostpine Creek is adjacent to the Threehills Creek basin (Figure 1.1). The creeks join before entering the Red Deer River. Research on the Ghostpine Creek originated in 1986 when Mr. Andrew Kopjar unearthed a semi-articulated prairie bison skeleton in terrace alluvium. This find prompted the excavation of the skeleton by Dr. James A. Burns of the Provincial Museum of Alberta, with assistance by Robert R. Young. Dr. R.

Bruce Rains became interested as the skeleton was located on terrace material in an area that had not been investigated to any degree prior to this.

The Holocene history of Ghostpine Creek (Rains et al. 1994) is very closely related to Threehills Creek and is somewhat similar to the tributaries of the North Saskatchewan River near Edmonton. Initially, Ghostpine Creek quickly incised nearly 20 metres through Glacial Lake Drumheller sediments, Laurentide till and then soft Cretaceous bedrock. This incision produced a longitudinal profile mirroring the partially convex-up form of many tributary creeks in Alberta (Rains and Welch 1988). The distal end of the Ghostpine Creek contains many strath terraces/pediments and residual spurs while a third of the way up the convex-up segment of the profile, the alluvium starts to accumulate forming terraces containing datable material. Terraces were developed upon the central third segment of the convex-up portion of the profile. The upper third of this segment is less incised and differentiation between the terraces becomes unclear and the creek's profile resumes the expected pattern.

Initial investigation identified three paired terrace sequences in the Ghostpine Creek. The incision into the valley after the retreat of the Laurentide ice was approximately 23 metres from about 13,000 yrs. B.P. to 8,000 yrs. B.P. However, with evidence from Michichi pond dated at 10,010 yrs B.P., the date of initial incision is in question (Young et al. 1993)

A bison bone fragment was found within basal gravels at a T-1 exposure. This fragment was dated at 7610 $\pm$ 70 yrs. B.P. and was buried by a nearly 2 metres of alluvium. Following the deposition of the specimen, a period of aggradation continued before phase 2 started. Not enough evidence has been found yet to delineate this period of incision and the start of the aggradation of T-2. This period probably did cover about 5,000 years but only recorded a 3-4 metre separation in terrace heights, with both terraces containing numerous oxbow scars. These scars indicate a meandering channel and lateral aggradation.

The semi-articulated remains of Kopjar's bison were dated at 2580 ± 90 yrs. B.P. It was found on a T-2 sand bar and buried quickly upon deposition, signifying a flood containing a large quantity of sediment. The burial time is recognized by Rains et al. (1994) as being close to the start of phase 3 degradation. The incision from the top of T-2 surfaces was approximately five metres before T-3 aggradation resumed.

The Phase 1 of Ghostpine Creek incised the valley at an approximate rate of 0.45 m/100 yrs. Phase 2 was much slower at a rate of 0.10 m/100 yrs and phase 3 was somewhat faster than phase 2 at 0.2 m/100 yrs (Rains et al. 1994).

2.5 Summation

The studies of the North Saskatchewan River show that the highest three terraces were probably caused by base level lowering as glacial lakes drained. The youngest terrace, T-4, has been developing over the last 8,000 years and is still being temporarily added to by peak floods depositing overbank fines.

The Rains (1969), Shelford (1975) and Welch (1983) investigations of the three respective creek basins draining into the North Saskatchewan River collectively showed different controls. This was highlighted by Rains and Welch (1988) in their comparative study of the three creeks. The controls in these creeks were not those of retreating glacial lakes creating new base levels in the North Saskatchewan River but, rather, Holocene climatic fluctuations. This is hinted at by slight variations in the recorded dates of each terrace sequence. Additional dates would pinpoint the terraces' ages, but they are difficult to obtain.

CHAPTER 3. GEOLOGY, SURFICIAL GEOLOGY, AND LATE GLACIAL HISTORY OF THREEHILLS CREEK BASIN

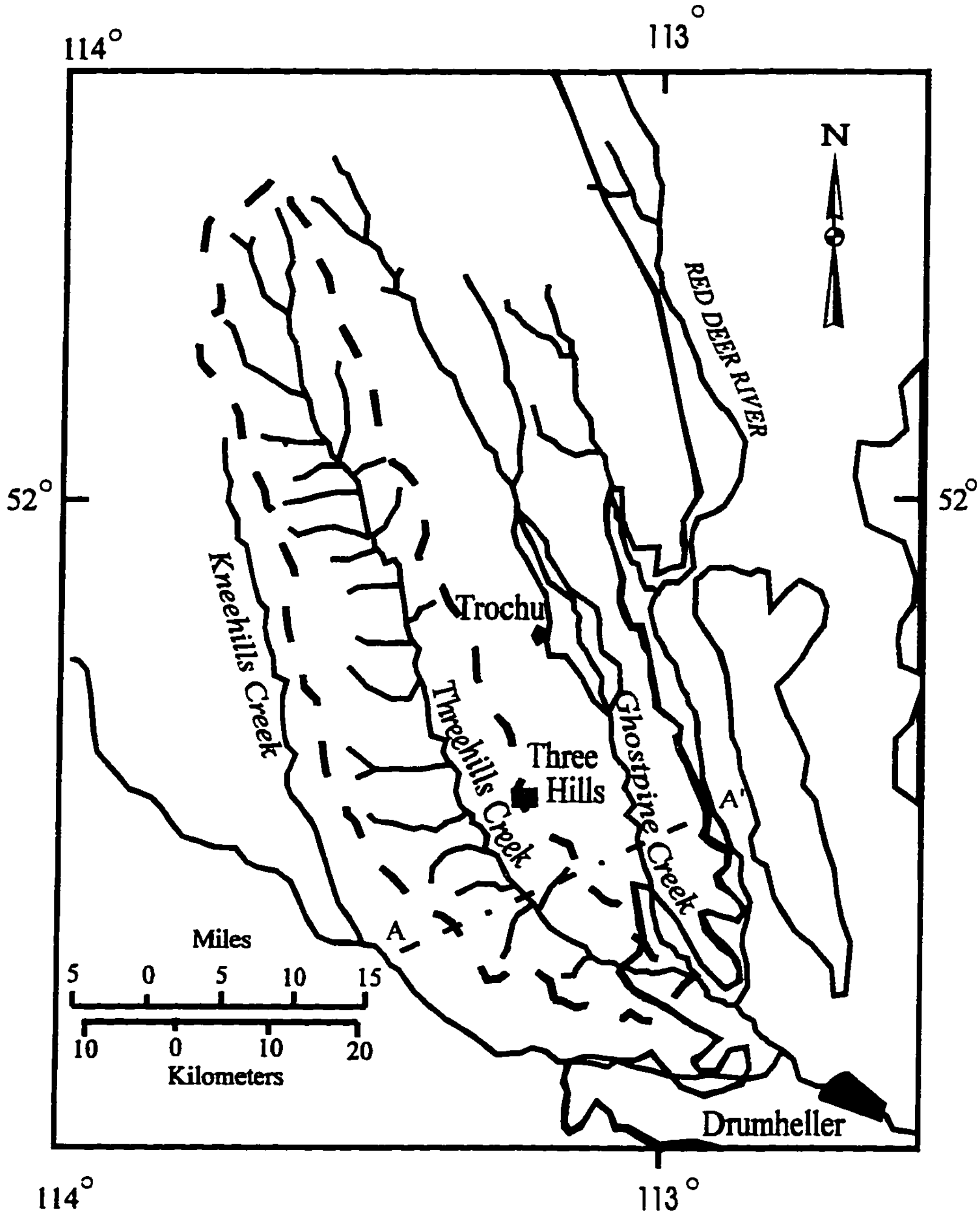
3.1 Introduction

The Threehills Creek basin is a result of long-term deposition and erosion. Sedimentation started with the great north American inland sea of the Cretaceous period depositing sediments in this area. This was followed by the deposition of freshwater sediment during the Paleocene, in the early Tertiary period. Evidence of further deposition after the start of the Paleocene was later removed by erosion. Folding and faulting during the Laramide Orogeny reshaped the landscape and Tertiary fluvial erosion ensued. Laurentide glaciation during Late Wisconsin time deposited till and glaciofluvial sediments over the Tertiary bedrock.

Deglaciation in this area had a significant depositional influence upon the basin. Proglacial lacustrine sediments were deposited at lower elevations of the basin, covering portions of the previously deposited Laurentide till. Minor meltwater channels developed between the basin ridges.

3.2 Bedrock

The bedrock in the Threehills Creek basin is from the Horseshoe Canyon and Paskapoo formations (Figure 3.1). The top of the Horseshoe Canyon Formation is late Cretaceous, approximately 68 million years (Ma) old (Folinsbee et al. 1961). The Paskapoo Formation is of lower Tertiary age, about 54 Ma old.



Threehills Basin divide

Line of cross-section A-A'

Paskapoo Formation (lower Tertiary)

Horseshoe Canyon Formation (upper Cretaceous)

Source: Stalker 1973, p. 10

Figure 3.1 Bedrock geology of Threehills Basin

Bedrock found along the southeastern part of the basin is of the Horseshoe Canyon Formation. It was created along the margin of the continental inland saltwater sea by deltaic and fluvial sedimentation. The dominant lithologies found in exposures of the Threehills Creek valley consist of interbedded grey and brown bentonitic shale. Bands of white and light grey "salt and pepper" feldspathic sandstone are evident but less pronounced in the exposures (Maslowski et al. 1986). Due to the high quantity of montmorillonite in the primary sand, the deposit was poorly indurated which resulted in a higher content of crystalline calcite which created a strongly cemented sandstone (Welch 1983).

The majority of Alberta's known coal deposits is found mainly in the lower portion of Horseshoe Canyon Formation (Maslowski et al. 1986). However, smaller seams of coal are visible in the upper part of the formation as well. The downstream portion of Threehills Creek valley contains seams that have been used by earlier local residents (personal comment. G. Gilford 1992). Coal fragments are also present in alluvium of the stream.

The Paleocene Paskapoo Formation (Figure 3.1) underlies the entire upland area of the Threehills Creek basin. The freshwater origin of this formation is partly reflected in the water quality of lakes in this area (such as Pine Lake, originally Ghostpine Lake) compared to the more saline lakes (e.g., Sullivan Lake) of areas to the east which are located upon Horseshoe Canyon Formation bedrock (Stalker 1973). Consisting of lenticular beds of sandstone, siltstone and claystone, the Paskapoo Formation rocks are coarser grained, darker colored, with less bentonite and thus more strongly cemented than the Horseshoe Canyon Formation sandstones (Welch, 1983).

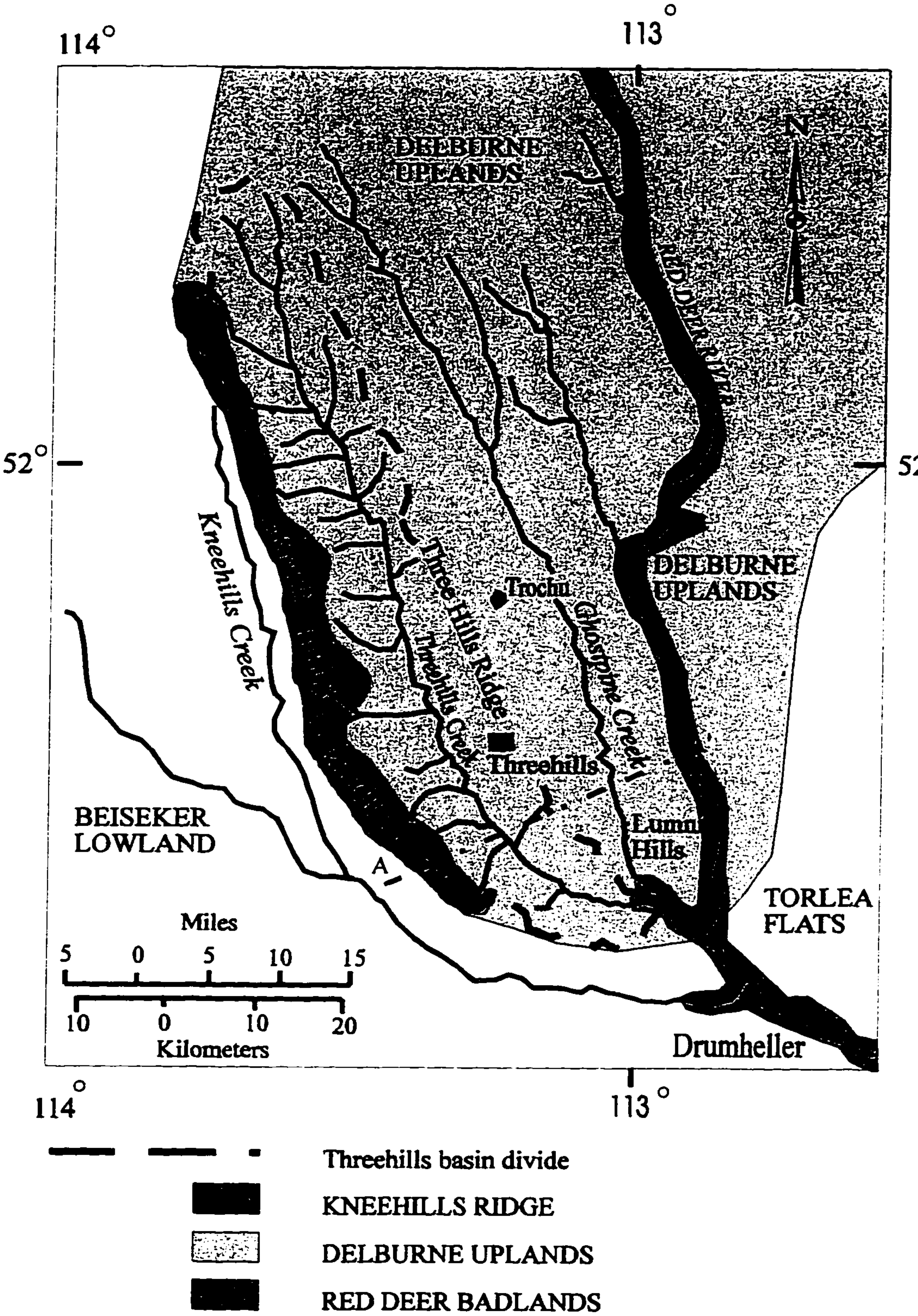
Paskapoo Formation sandstones can be found along the Threehills Creek and in places on local uplands, usually in roadcuts.

3.3 Orogeny

The horizontal layers of sedimentary bedrock that formed in west-central Alberta were mildly affected by the Laramide orogeny of the Rocky Mountains. This tectonism created a parallel relationship between the Rocky Mountains, Foothills ridges, and some of the Plains preglacial valleys that were developed (Stalker 1973). The local expression of the orogeny is found in steeper slopes from the top of Threehills Ridge westward. into the drainage basin. This is contrasted by the longer, gentler slopes from the top of the Kneehills Ridge eastward (Figures 3.2 and 3.3). This pattern is repeated in the Ghostpine drainage basin as well. Tertiary fluvial erosion may also have added to the cross-sectional asymmetry (personal comment, Rains 1996).

Kneehills Ridge (Figure 3.3) separates the Kneehills Creek drainage basin from that of the Threehills basin along a northwest to southeast line, heading more easterly near the southern end of the basins. closer to its confluence with the Red Deer River. The Kneehills Ridge high point is 1007 metres above sea level (m a.s.l.), just south of Highway 582 on Sec 11, Twp 31, Rge 25. The majority of the ridge runs at about 925 m a.s.l.

The Threehills Ridge separates the Threehills Creek drainage basin from that of the Ghostpine Creek basin. The most obviously prominent point on this ridge is at just over 950 m a.s.l.and is known as the Three Hills (Figure 3.3) north of the Town of Three Hills. The average height of the ridge is around 915 m a.s.l.



(Source: Stalker 1973)

Figure 3.2 Physiographic divisions of Threehills drainage basin

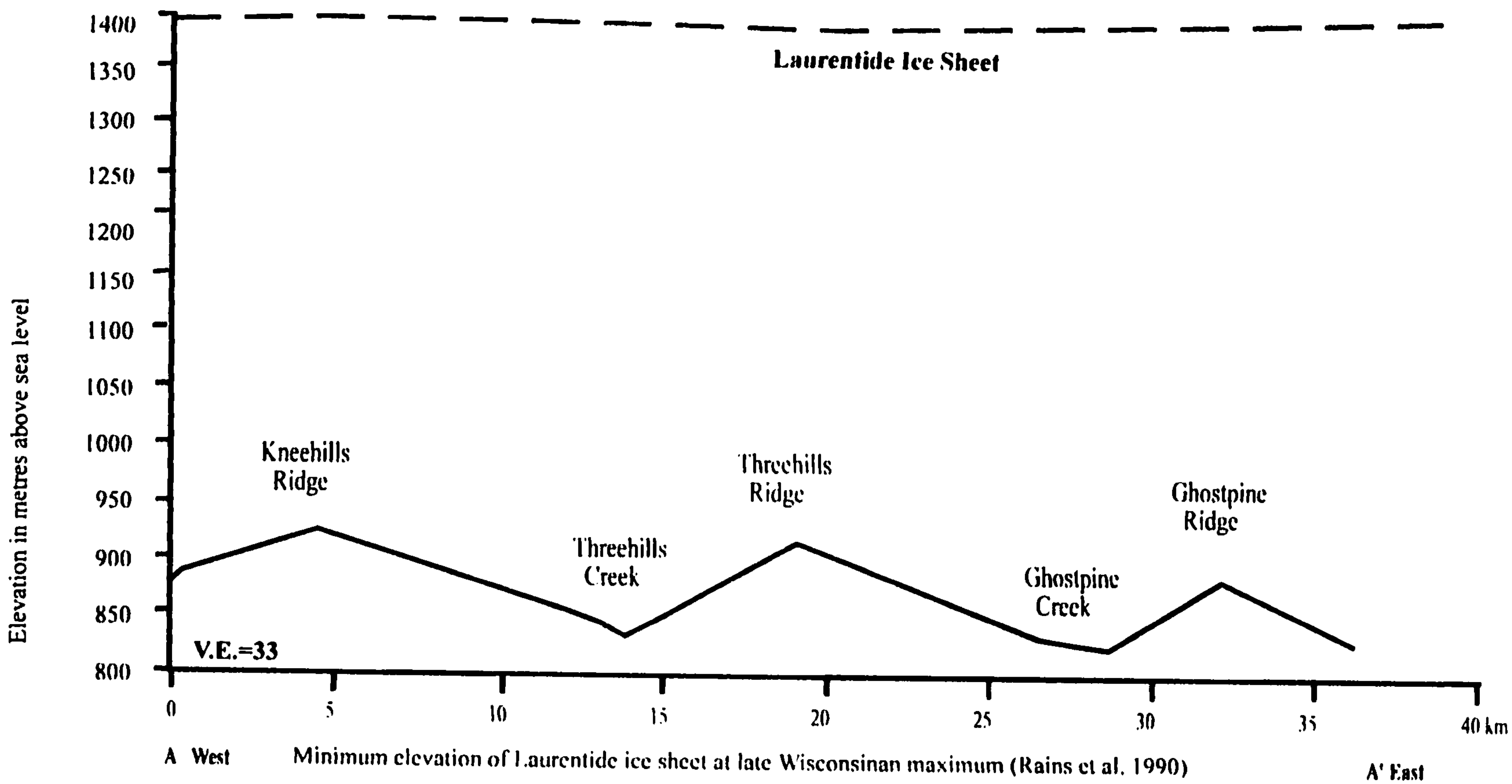


Figure 3.3 Topographic cross-section of Threehills Creek Basin A to A'

Ghostpine Ridge (Figure 3.3) separates Ghostpine Creek from smaller unnamed intermittent creeks that flow into the Red Deer River. The average height of the ridge is 885 m a.s.l with a high in the southern part of the ridge just over 915 m a.s.l. in the Lumni hills (Figure 3.3) area on Sec 10, Twp 32, Rge 22 W. of 4.

3.4 Laurentide deglaciation

Initially Laurentide ice advanced upslope from the Keewatin district, NWT, into Alberta. It is probable that ice from the Keewatin domain arrived in southwestern Alberta approximately 22,000 yrs B.P. Subtill radiocarbon dates on bone and wood (retrieved from alluvial gravel and sand in the Handhills region) are the basis of that interpretation (Young 1991, Young et al. 1994). Well west of the study area the Laurentide and Cordilleran ice masses are interpreted to have coalesced and reached a minimum surface elevation of about 1,400 m a.s.l. (Figure 3.3) (Rains et al. 1990) and Laurentide ice reached its maximum southwestern extent, in Montana, by about 18,000 yrs. B.P. (Dyke and Prest 1987). Ice hundreds of metres thick would then have covered all three local basins and ridges during this period (Figures 3.2 and 3.3).

Later thinning and retreat of Laurentide ice exposed the northern portions of the Ghostpine, Threehills, Kneehills and Rosebud basins above the 830 m to 860 m contour levels (Stalker 1973, Shetsen 1987). During this period of stagnation, it is probable that some of the ground moraine was deposited. These deposits are to be found on most of the highlands of the basin and Delburne Uplands (Figure 3.2).

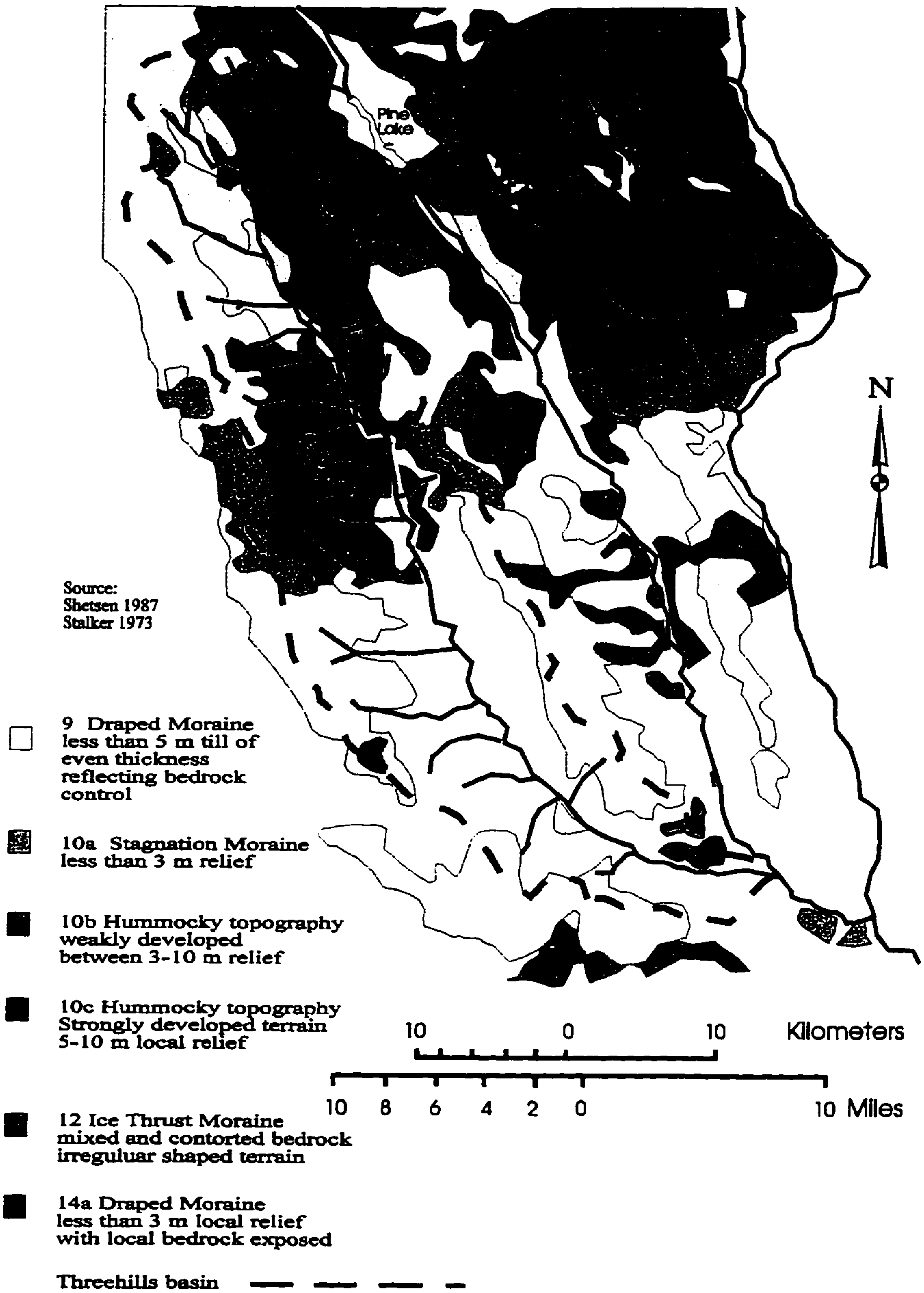


Figure 3.4 Glacially deposited material in Threehills basin

3.4.1 Glacial Lake Beiseker

After about 14,000 yrs B.P., deglaciation in southern Alberta proceeded more rapidly. The chronology of proglacial lake drainage suffers from lack of dates to make it more accurate (Stalker 1973, Klassen 1993). Wasting Laurentide ice generally blocked drainage of meltwater to Hudson Bay. Most seasonal and glacial runoff traveled the southern edge of the glacier until it drained via the Missouri, James, Des Moines, and Minnesota valleys into the Mississippi River system (Stalker 1973, Dyke and Prest 1987, Shaw et al. 1996).

Glacial Lake Beiseker, formed immediately south of the Threehills basin, in the area of the Beiseker lowlands (Figure 3.3). Its drainage was controlled to the south by Glacial Lake Bassano and Glacial Lake McGregor. Glacial Lake Beiseker's highest level was around the 950 m a.s.l. (Stalker 1973). Episodic lowering of the lake occurred at approximately 30 metre intervals, approximately every 250 years (Stalker 1973). The first episodic lowering caused Glacial Lake Red Deer to the north to cease drainage into Glacial Lake Beiseker. Flow to Glacial Lake Beiseker was then contributed mainly from the upland basins of the Rosebud, Crossfield and Carstairs basins with lesser amounts from the ponding at the Threehills, Kneehills and Ghostpine basins.

The outlet from the Threehills pond to the Kneehills pond is a narrow channel 11 km (7 miles) northwest of Carbon, visible west of Highway 21 (TK, Figure 3.5) (Stalker 1973). Glacial Lake Beiseker was draining south at this time over the Tudor outlet 9.5 km (6 miles) east of Rockyford. The formation of Glacial Lake Beiseker, until it flooded the lower half of Serviceberry Creek and joined with the rest of Glacial Lake Drumheller, occurred at ~13,750 yrs B.P. (Stalker, 1973).

Thinner stagnant ice over the Delburne Uplands, Kneehills Ridge and Threehills Ridge (Figure 3.3) melted and water was dammed in the Threehills and Ghostpine valleys by the thicker ice to the east. As water was added to these proglacial ponds from glacier and surface runoff, spillways were formed over the ridges, joining the ponds in the Threehills and Ghostpine basins (GT, Figure 3.5). These glacial ponds joined Glacial Lake Beiseker at about 923 m a.s.l. (Stalker 1973). After the lowering of Glacial Lake Beiseker to an elevation of about 900 m a.s.l., the water in the Threehills Creek basin sat at 908 m a.s.l. and was separated from the Ghostpine basin by the bedrock ridge. Slight drainage over the ridge, through spillways, into Glacial Lake Beiseker did occur as the ponds corresponded in height to Glacial Lake Beiseker at the 900 metre level ~13.500 yrs B.P. (Stalker 1973)

Coarse sediment (2a, Figure 3.5) was deposited in the Threehills Creek basin during the period of deposition when the pond sat at 923 m a.s.l. Finer sediments were deposited lower in the basin during the ponding of Glacial Lake Drumheller.

3.4.2 Glacial Lake Drumheller

The first system to be called Glacial Lake Drumheller was located north of the current City of Drumheller in the Michichi Creek area, on Twp 30 and 31, Rge 19, W of the 4th Meridian. The furthest extent of Glacial Lake Drumheller included large ponds in the Kneehills. Threehills and, Ghostpine valleys and Glacial Lake Mudspring (located east of the Red

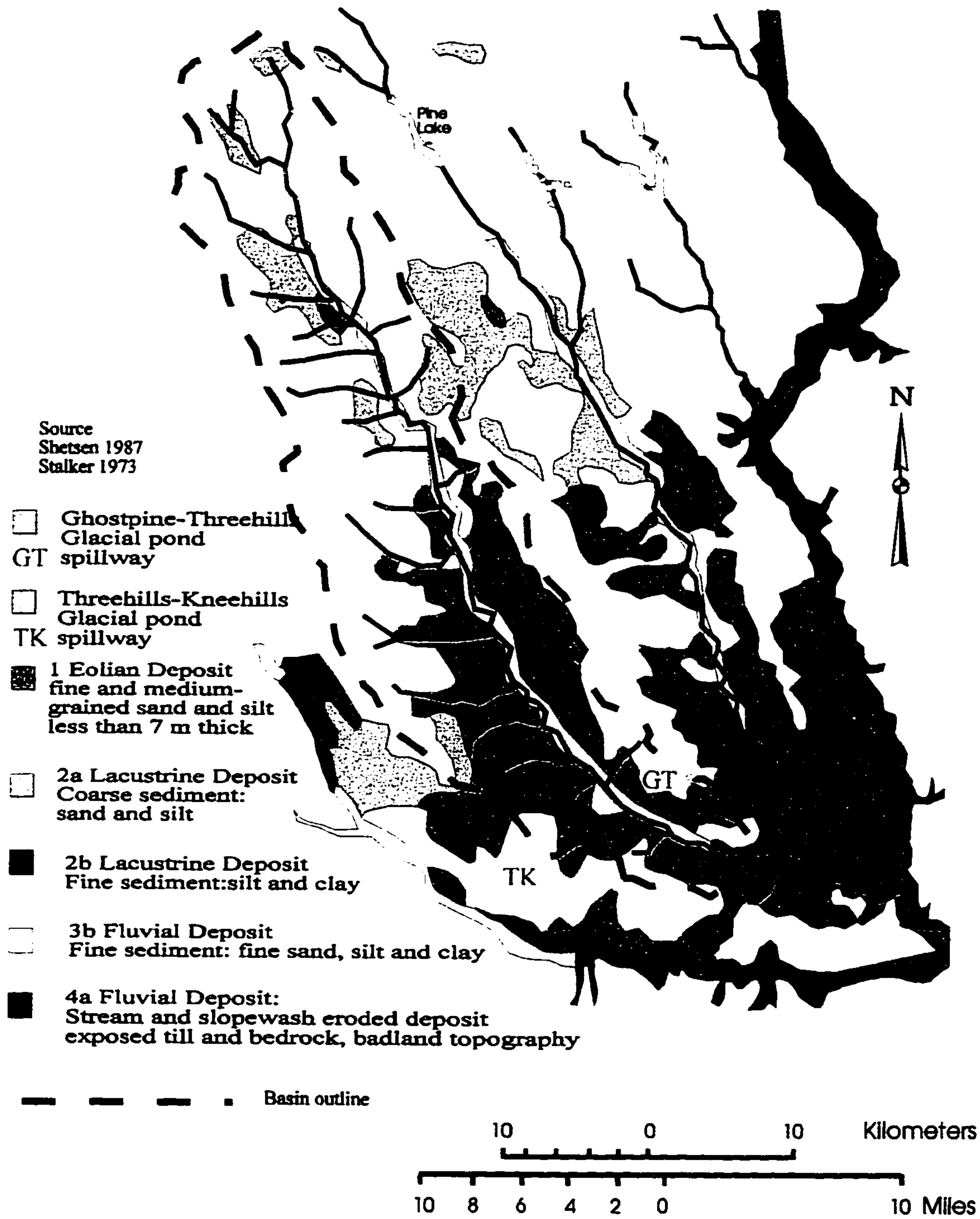


Figure 3.5 Late Pleistocene and Holocene lacustrine, fluvial and eolian deposits in Threehills basin

Deer River centered near the Town of Rumsey) and the remnant Glacial Lake Beiseker. They were joined at about 853 m a.s.l. ~13,500 yrs. B.P. (Stalker 1973). This date is estimated from Glacial Lake Agassiz which started to form as drainage south through the Missouri system was limited by bedrock highs (Dyke and Prest 1987, Klassen 1994).

Drainage of Glacial Lake Drumheller through the Red Deer River was over smaller outlets west of Crawling Valley into Glacial Lakes Bassano and Gleichen. The erosive power of the Red Deer River over the Crawling Valley lowered the initial outlets level from the 890-830 m a.s.l., making the Crawling Valley the major spillway for Glacial Lake Drumheller. As ice retreated further east. the Crawling Valley was abandoned and the Gem spillway became the outlet for Glacial Lake Drumheller.

The draining of Glacial Lake Drumheller occurred ~13,000 yrs B.P. (Stalker 1973). Threehills basin was significantly far enough from the furthest extension of the glacial lake that this event did not erode the basin significantly. Smaller systems were left behind, such as glacial ponds Threehills, Ghostpine, Mudspring and Michichi. The latter has tentatively been radiocarbon dated (gastropods) at 10,010 $\pm$ 70 yrs B.P. (Young, et al. 1993). This would indicate that these ponds persisted for up to 3,000 years before finally draining, allowing initial stream incision to develop across their beds.

CHAPTER 4. THREEHILLS CREEK TERRACES; MORPHOLOGY, STRATIGRAPHY AND CHRONOLOGY

4.1 Introduction

This chapter sets out the Holocene geomorphic evolution of Threehills Creek valley. The spatial relationships of remnant terraces were measured to determine their development within the system, and thus its chronology. Terrace remnant distribution along valley walls, their relative elevations and their elevations above the present channel all contribute to understanding how the system evolved through aggradation and degradation.

The planimetric distribution of terrace remnants along the valley was mapped, the longitudinal profile of the channel charted, and the elevations of the remnant terraces measured above this profile. Cross-sectional profiles were also compiled to present change along the valley as the system evolved. Stratigraphy was examined to understand and confirm the geomorphic processes that took place. Datable material was collected and logged and radiocarbon dated to help in building the chronological history of Threehills Creek basin.

4.2 Distribution and Morphology of Alluvial Terraces

Environmental stability within a fluvial system creates paired terraces. However, finding paired terraces is not always common. Along the valley terrace remnants with similar elevations above the modern creek profile help to create sets of terrace sequences or suites (Figures 4.1 to 4.6)

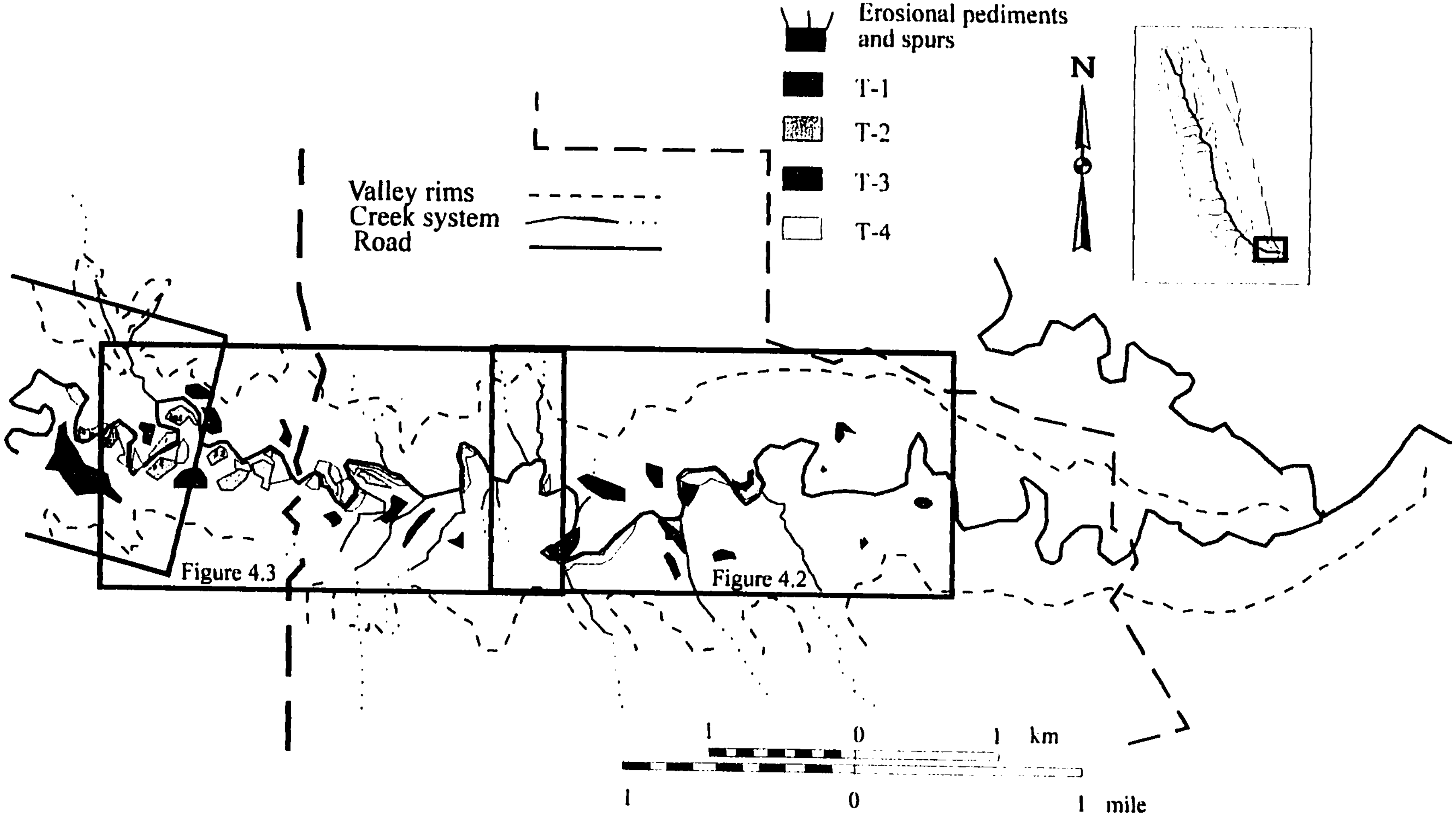


Figure 4.1.a Location of planimetric terrace maps.

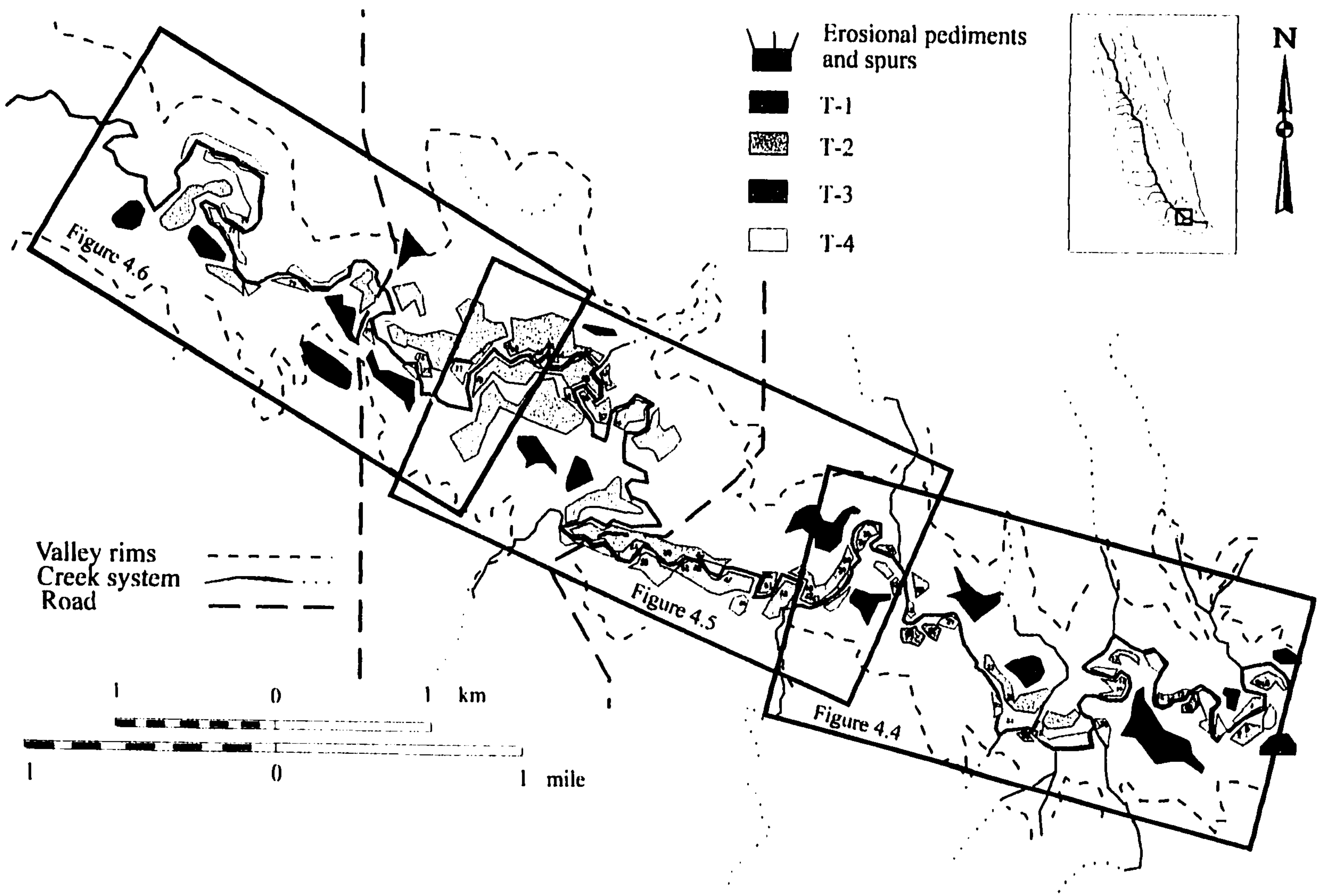


Figure 4.1.b Location of planimetric terrace maps.

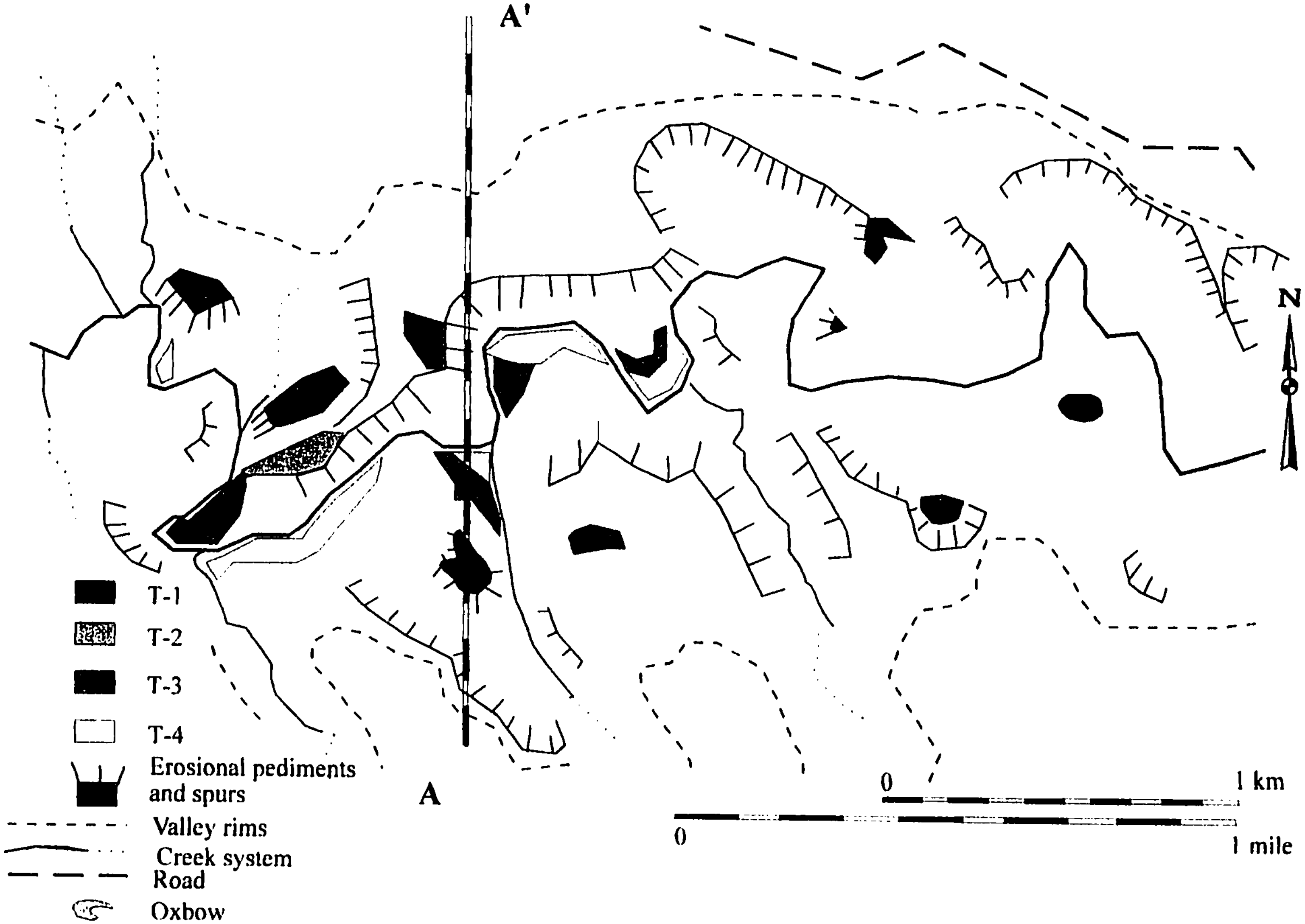


Figure 4.2 Planimetric distribution of terrace remnants.

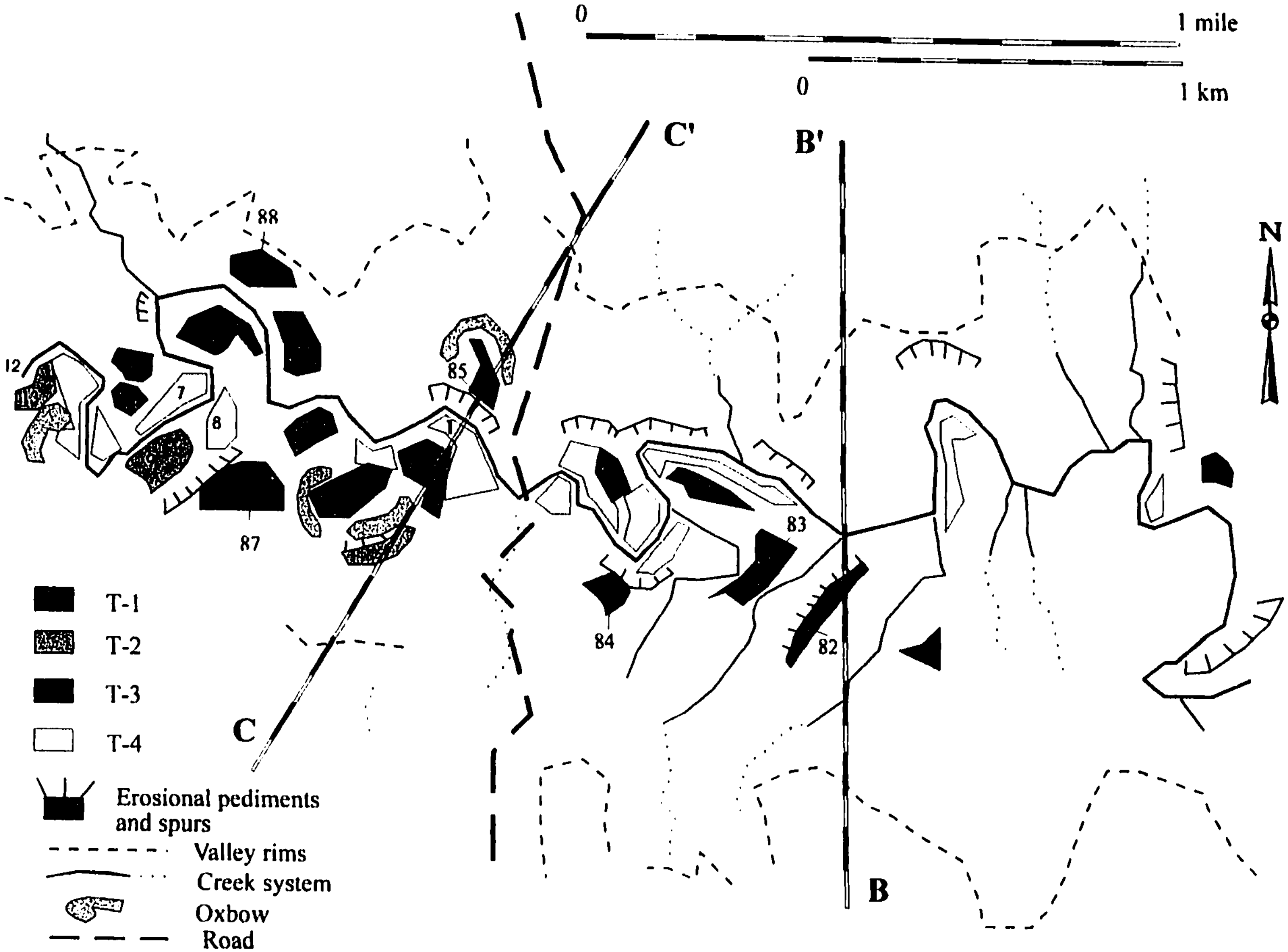


Figure 4.3 Planimetric distribution of terrace remnants

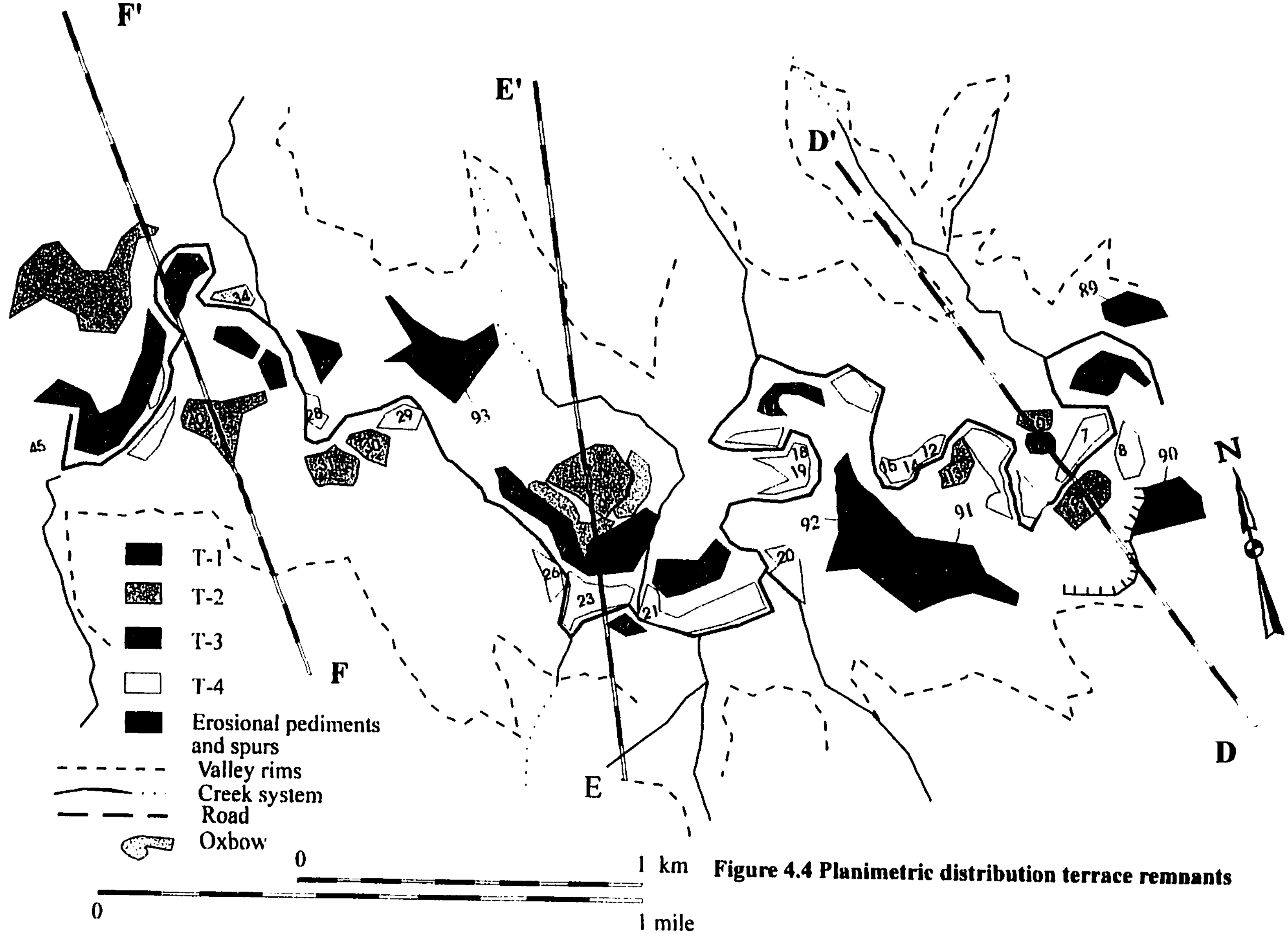


Figure 4.4 Planimetric distribution terrace remnants

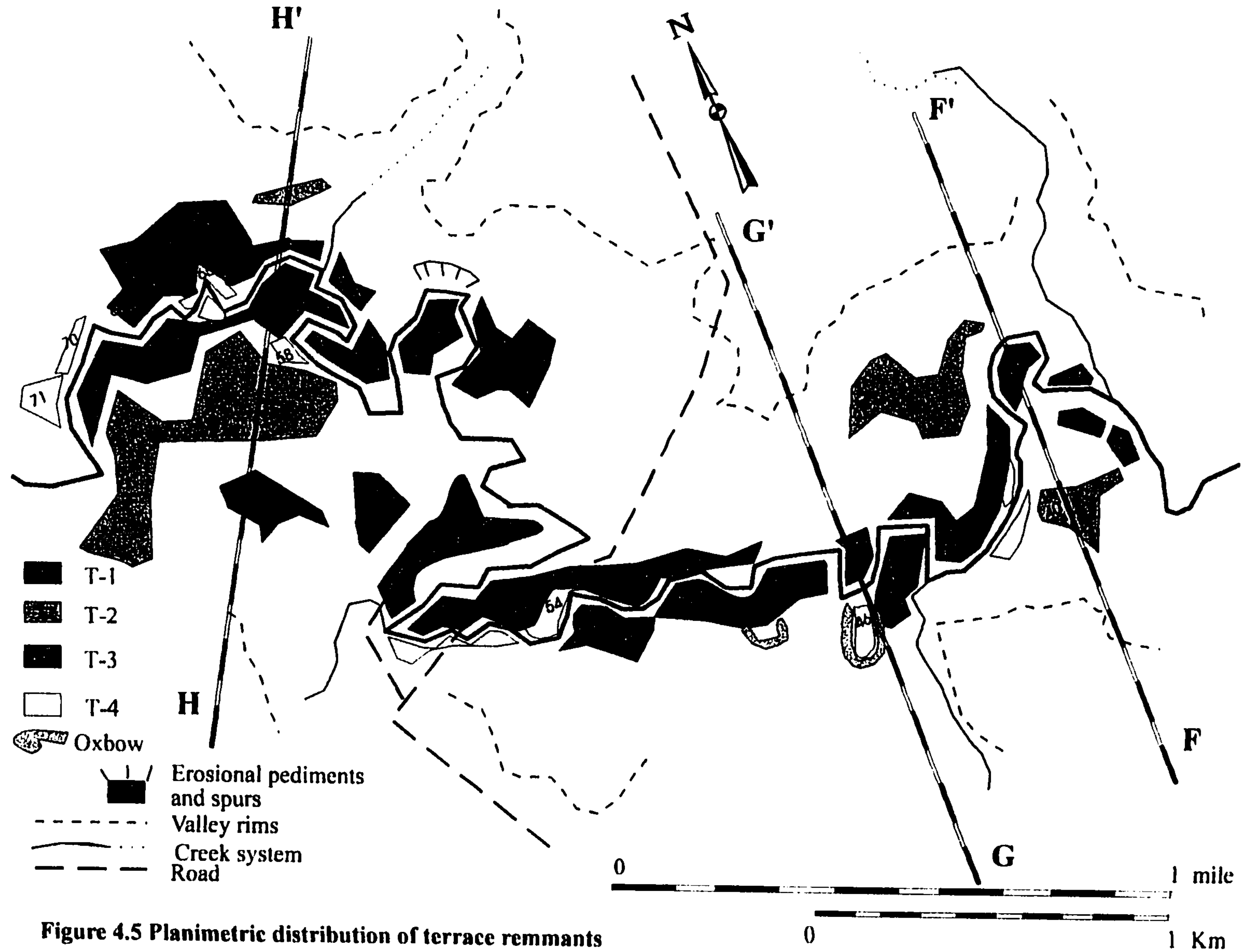


Figure 4.5 Planimetric distribution of terrace remmants

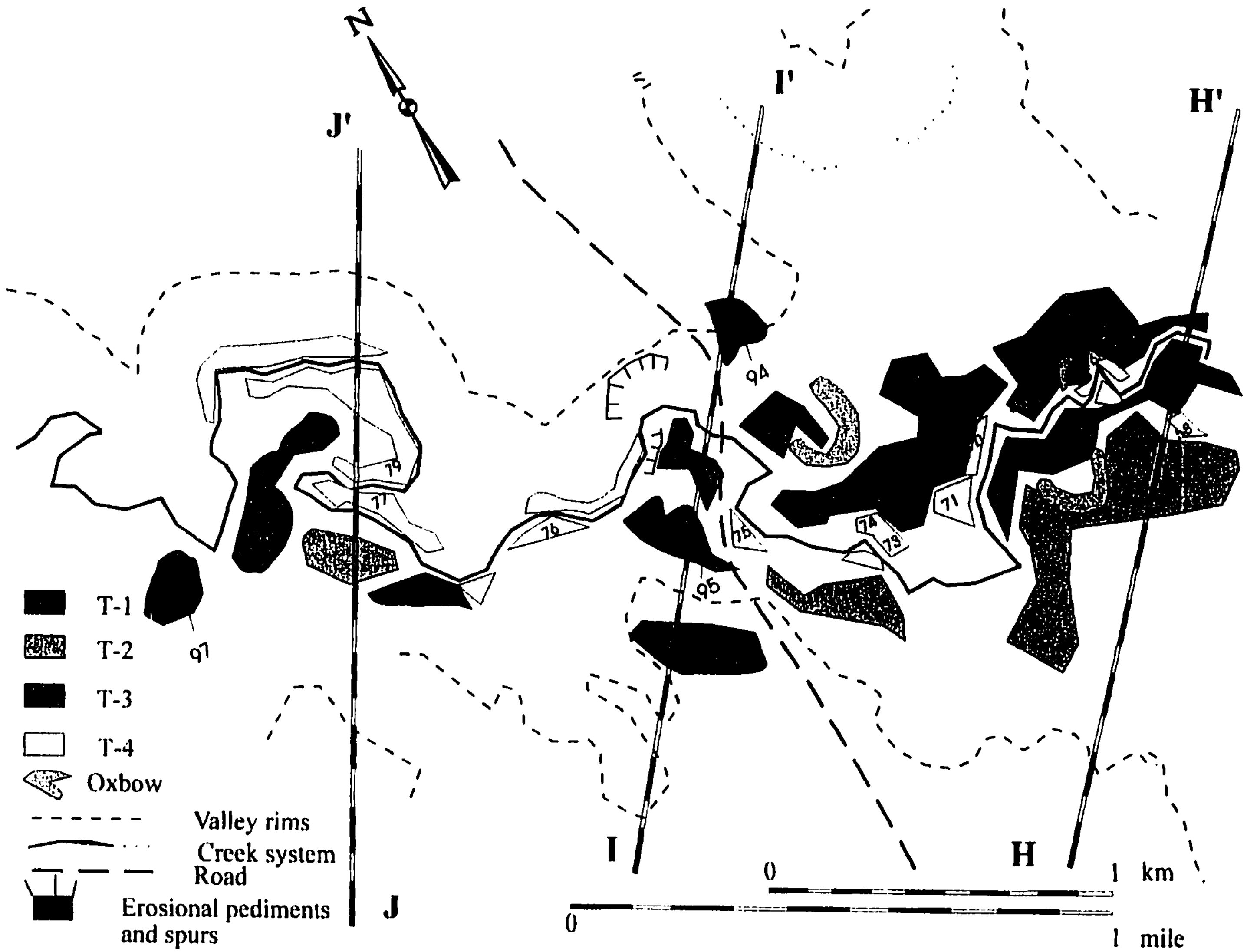


Figure 4.6 Planimetric distribution of remnant terraces

Each suite of terrace remnants indicates a period of geomorphic stability, when aggradation of the modern floodplain dominated in the system.

Figures 4.1.a and 4.1.b present the location of the planimetric maps of Threehills Creek valley, Figures 4.2-4.6. The latter depict the areal distribution of four paired terrace treads with their terrace designations. The terrace designations, based on the criterion of relative height, are T-1 (oldest), T-2, T-3, and T-4 (youngest and modern floodplain). Generalizations which may be made about the planimetric distribution of terrace remnants in the Threehills Creek valley are as follows:

(1) The majority of T-1 units were logged and 12 T-1 remnants were mapped (Figures 4.2-4.6). These terraces were designated T-1 as their elevations were consistently paired.

(2) More T-2 remnants are found along Threehills Creek and they are not limited to the valley walls. Exposures along the creek allowed 27 of these units to be documented.

(3) T-3 sections are more abundant and 36 sections were logged. These terrace remnants are found over wide areas between the valley walls. The only difficulty in differentiating T-3 and T-4 occurred upvalley where minor differences in elevation caused some confusion.

(4) Though most abundant, only 15 T-4 sections were logged. Logging was done where datable material was found. Where accretion has taken place over the last three to four hundred years, a discernible terrace has formed. The modern flooplain and T-4 are synonymous.

(5) In the study area, mapped terrace surfaces have a significant horizontal extent. Paleo-channels affected the relief of some of the terraces and have even been utilized by intermittent streams from the valley walls.

(6) From the confluence of Threehills Creek with Ghostpine Creek, upstream to east of Highway 836, the majority of the remnant terraces lack significant extents of horizontal tread. Badlands, with erosional pediments, spurs and alluvial fans resulting from stream incision made this section of the stream difficult to log.

(7) Upstream from section 78 (Figure 4.6), widening of the valley created a more lateral migration of Threehills Creek allowing for vegetation and slumping to prevent further logging.

4.2.1 Longitudinal Profile

As noted in Chapter 2, the form of the longitudinal profile reflects a number controls on creek development (Leopold et al. 1964, Schumm 1993). The Threehills Creek longitudinal profile (Figure 4.7) is concave-up in the majority of the upstream portion of the profile, and convex-up in the downstream section. Generally creeks evolve concave-up long profiles. When an atypical convex-up profile is discovered, several geomorphic variables such as lithology and ephemeral discharge may be responsible.

Threehills Creek bedrock (Figure 3.1) shows the transition from Paskapoo Formation in the west, to Horseshoe Canyon Formation in the east. Both are sedimentary rock formations, including sandstone, shale and coal, and are easily erodible. Threehills Creek bisects the formation-boundary near the cusp of the concave-convex transition of the longitudinal profile. This might indicate that the change in bedrock caused the change in the longitudinal pattern.

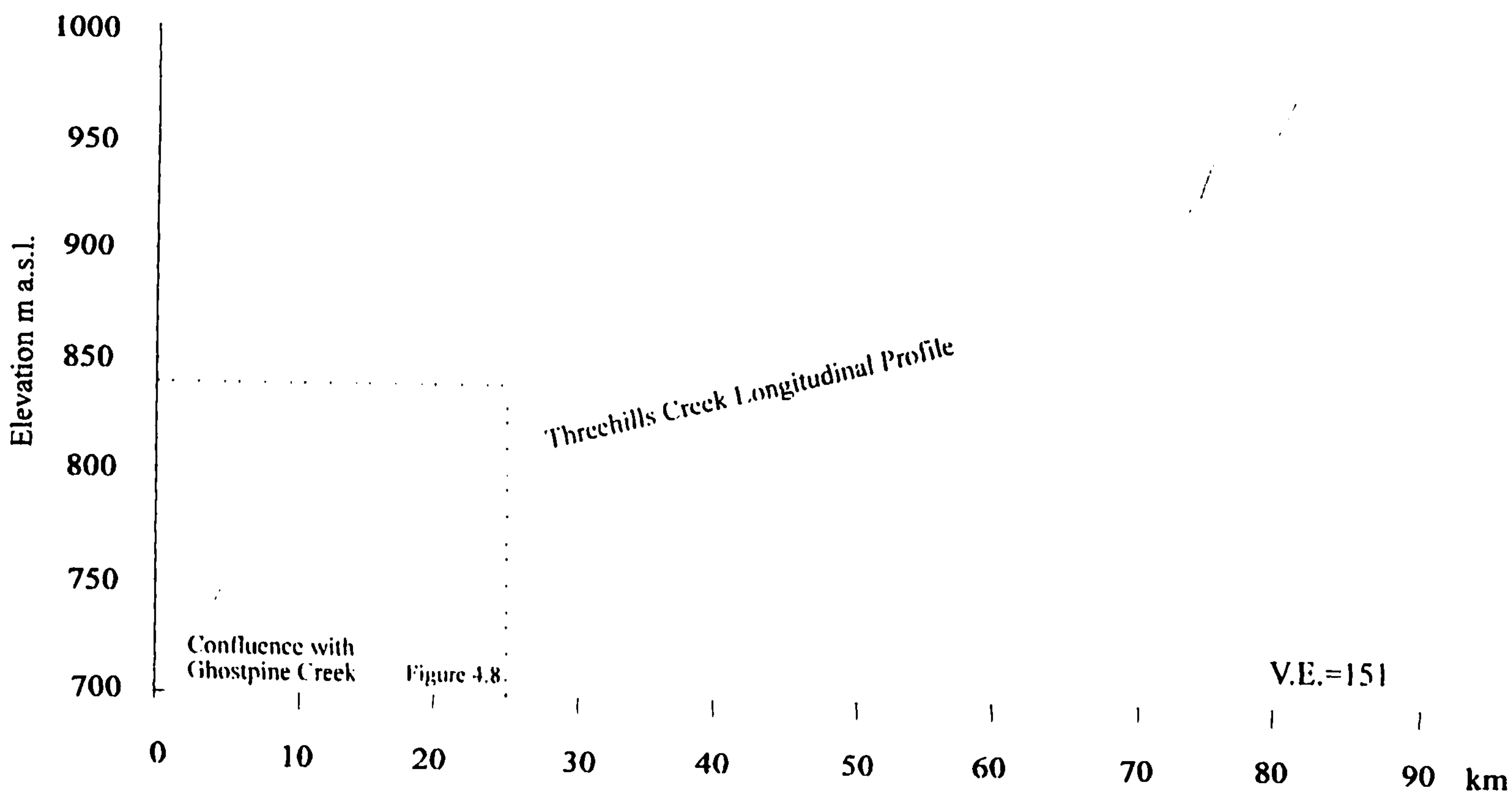


Figure 4.7 Longitudinal channel profile of Threehills Creek

When the longitudinal profiles of Threehills Creek and Strawberry Creek are compared (Figures 4.7 to 4.9) the similarity is obvious. However, Welch (p.44 1983) found in the Strawberry Creek basin a similar change of bedrock lithology from Paskapoo to Horseshoe Canyon formations. In his geologic cross-section, the formation boundary is well upstream of the transition in the channel profile and only a slight change in profile is noticeable at this boundary. Therefore, it can be concluded that proximity of the formation boundary of Threehills Creek and the transition from concave to convex longitudinal profile is more coincidence than a result of bedrock control.

The concave-up profile in most of the upstream reach of Threehills Creek (Figure 4.7) is typical of prairie streams (Rains 1969, Shelford 1975, Welch 1983, Rains and Welch 1988, O'Hara and Campbell 1993). The shorter, convex-up pattern in the downstream section of the stream is also typical of many northern prairie streams of similar size to those studied by Rains (1969), Shelford (1975), Welch (1983), and Rains and Welch (1988).

4.2.2 Longitudinal Profile with Plotted Terrace Heights

Paired terraces are terraces that are closely matched in elevation above and along a longitudinal profile. In a meandering system unpaired remnants occur between suites of paired terraces. It is along the charted longitudinal profile (Figure 4.8) that the pattern of four terraces suites is distinguished. Upstream convergence of terraces is noticeable, initially the third and fourth terrace remnants, then the second and finally the first.

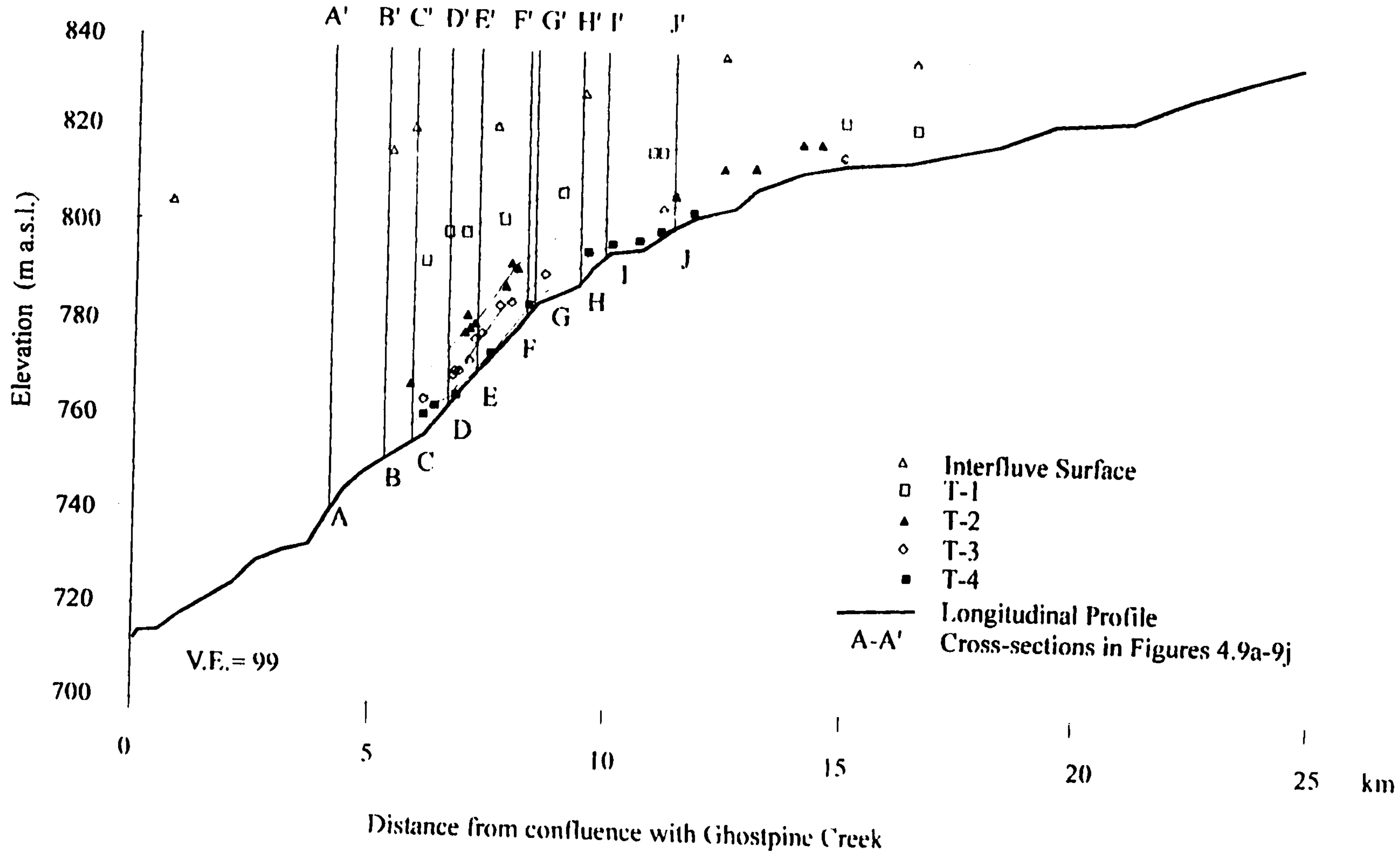


Figure 4.8 Plotted terrace heights above Threehills Creek channel profile

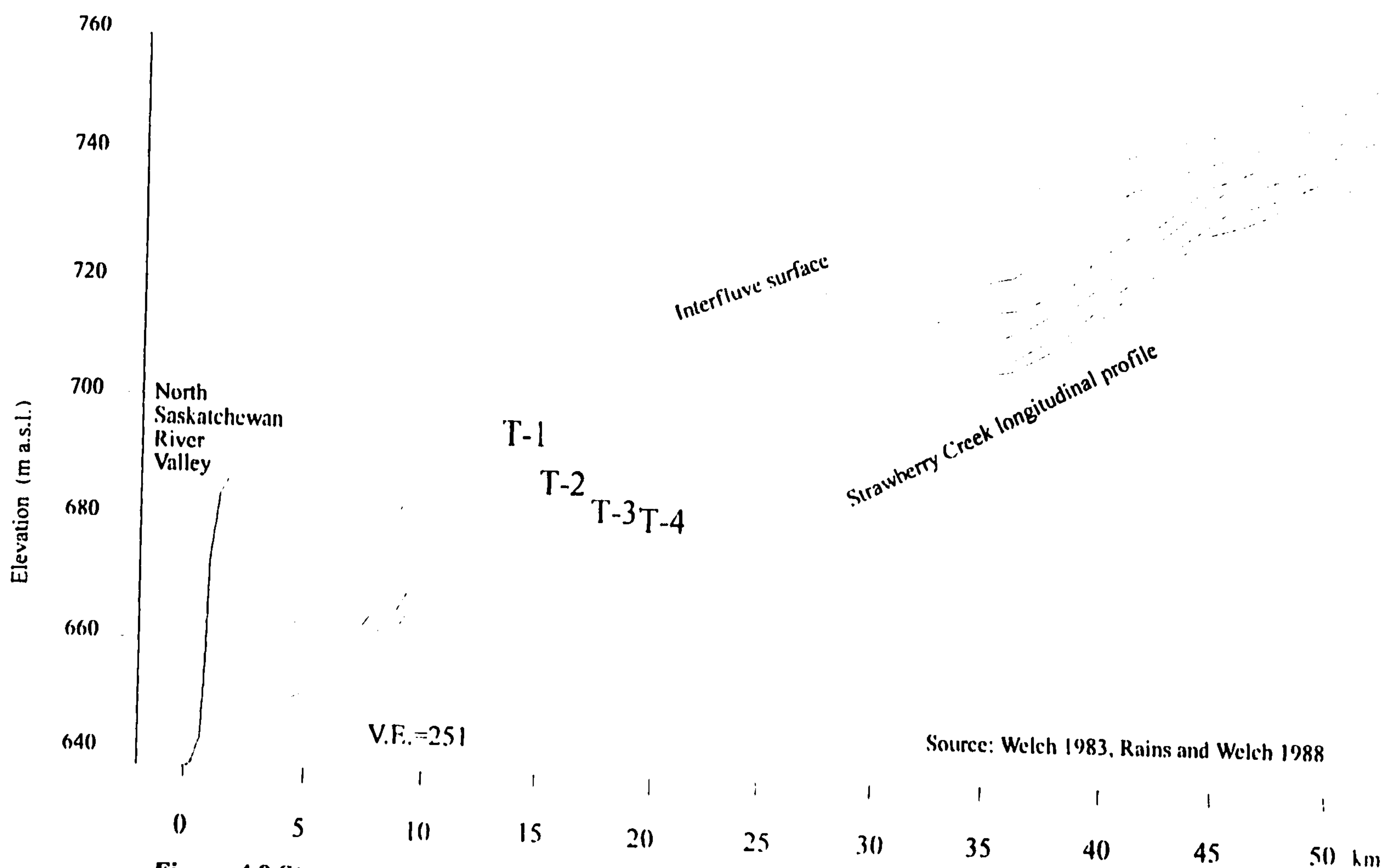


Figure 4.9 Strawberry Creek: Terrace remnants plotted against longitudinal profile

4.2.3 Cross-section Profiles and Plotted Terrace Heights

During the earliest phase of stream development, erosive action of Threehills Creek was not obstructed by valley walls. This allowed the stream to move laterally over a large area, constrained only by the topography of the initial basin surface.

Cross-section A-A' in Figure 4.10a shows this early lateral movement of Threehills Creek in the slope of the upper valley walls. The unconstrained lateral movement covered an extra 400 m (Figure 4.10.a, 1200 m to 1600 m mark) of the current north valley wall before the stream embedded itself. From the inital entrenchment to the present day the valley bottom has narrowed from 1000 m to 600 m. With lateral movement concentrated in this narrow valley, incision became the predominant form of erosion creating steep 70 m valley walls. A 30 m high erosional pediment is isolated by the incision of Threehills Creek in this cross-section.

At cross-section B-B' (Figure 4.10.b) the meandering of the early Threehills Creek is not in evidence with the tops of the valley walls separated by ~1 km. The creek has incised the valley ~70 m and the floor is about 600 m wide. The top of an erosional pediment tread is 40 m above the present channel. It was initially isolated by an oxbow which has been further eroded when it was captured by an intermittent stream. Incision by this stream created a 20 m deep, V-shaped valley between the valley wall and the remnant ridge.

Stream incision from the valley walls to the present channel is ~60 m at section C-C' (Figure 4.10.c). The relic oxbow indicates the creek's historical lateral movement covered a width of 1200 metres. The top of the isolated T-1 remnant is ~18 m below the valley surface and the oxbow that isolated the remnant is 11.5 m below the top of the T-1 remnant. A steep 31 metre cliff from the oxbow to the present stream bed contained the stream to a narrower ~800 metre wide valley. An erosional pediment in this section of the valley was also isolated by an oxbow and has only a thin layer of fluvial material on it. The T-3 stands 5 m above the current stream bed and the T-4, 2 m above the bed.

At D-D' the south valley rim drops sharply ~40 m from the valley surface to the floor. On the north side, lateral movement of the stream created a gentler slope before incision created a steeper ~25 m valley wall. The width of the valley bottom at this cross-section (D-D', Figure 4.10.d) is ~675 m. The three lower terraces are well represented here with paired T-2 remnants on both sides. An exposure of the southern T-2 contained datable material. Part of the cross-section to the north (D') is indicative of a V-shaped intermittent feeder stream.

The valley-top width at cross-section E-E' (Figure 4.10.e) is over 1300 m. The northern valley wall reflects more gradual lateral migration and the steeper southern valley wall of 54 m reflects substantial undercutting. All four terraces are represented in this cross-section though the T-3 is relatively small. The T-1 remnant at 25 m below the valley rim was either being formed at a later time than other T-1 remnants or lateral erosion during the following stage of degradation may have removed some of the fluvial material. Alternatively, it could also be an unpaired terrace between T-1 and T-2. The valley wall to the north of the T-1 is separated by 800 m from the south valley wall.

The valley depth at cross-section F-F' (Figure 4.10.f) is 35 metres. A pair of T-1 remnants are definable by their elevation and surface tread, but neither reveals exposed alluvium. The T-2 here is encircled by the present stream.

Section G-G' (Figure 4.10.g) shows the valley width at the top to be ~900 m and at the bottom ~700 m. The predominant activity of the creek at this point is the consistent lateral movement, eroding terrace remnants. The paired T-3 remnants along the north valley wall are separated by meander scars.

Cross-section H-H' (Figure 4.10.h) presents a 30 m deep valley with a gentler south slope. Incision appears to have increased as a change of slope on the south wall indicates more rapid incision and development of more defined valley walls. The matched T-3's of this cross-section are representative of the most recent lateral migration of this creek.

Cross-section I-I' expresses a unique physiographic section with the valley walls narrowing to >400 m. Two paired T-1 remnants, both containing Mazama ash in their exposures, are separated by the modern creek. At this unique spot is also the location of the D.O. Irving farmstead. Here the Irvings placed field cobbles and boulders along the T-4 and T-3 bank upstream of the farm site and the cross-section to protect the farm site from being eroded. This has forced lateral migration to the north of the farm site and a slump has since resulted.

This was also the site of an earlier First Nations bison jump. Burn pits with charcoal were discovered when the front lawn of the house was developed and large quantities of bison bone were also discovered while auguring post holes for the current farmyard corrals (personal comment, Mrs. Irving, 1993, 1995). The undulating valley wall represented by the I-I'line north of the modern creek is the intersection of an intermittent stream and relic oxbow.

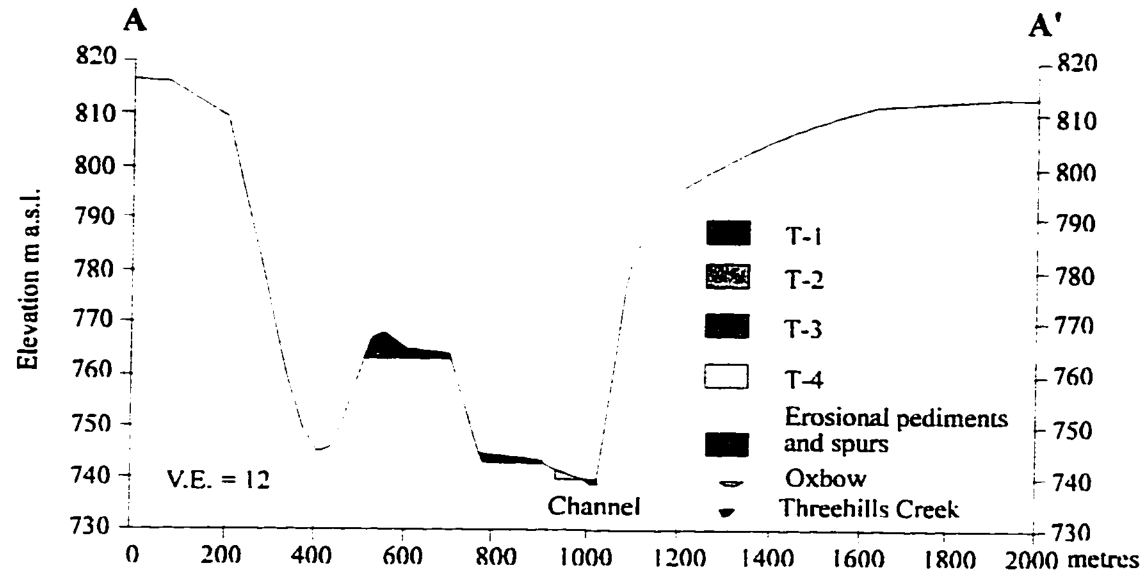


Figure 4.10.a Valley Cross-section A-A' (see Figure 4.2 for location)

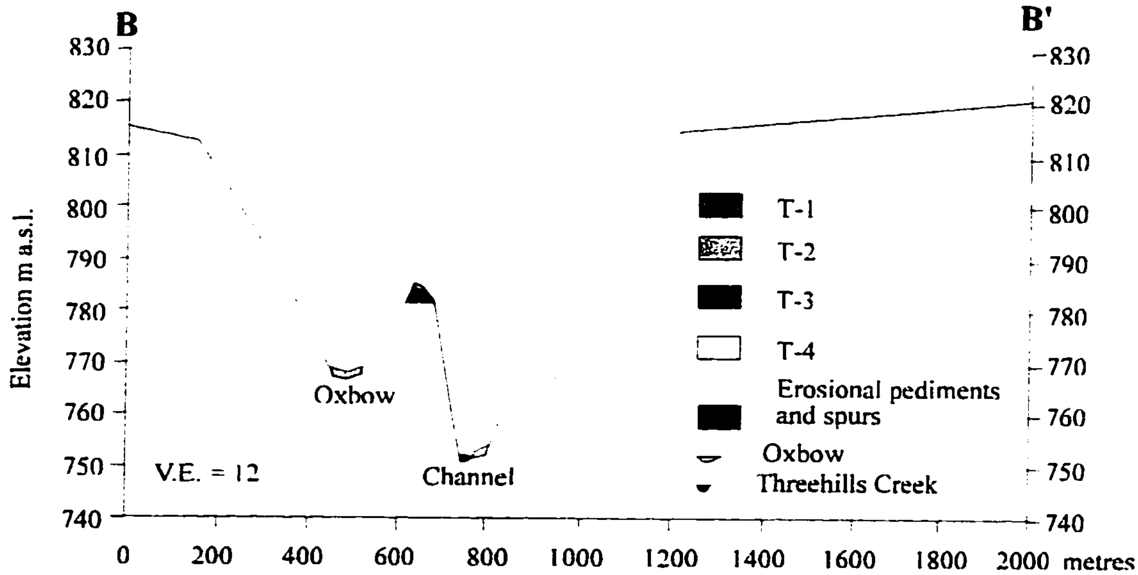


Figure 4.10.b Valley Cross-section B-B' (see Figure 4.3 for location)

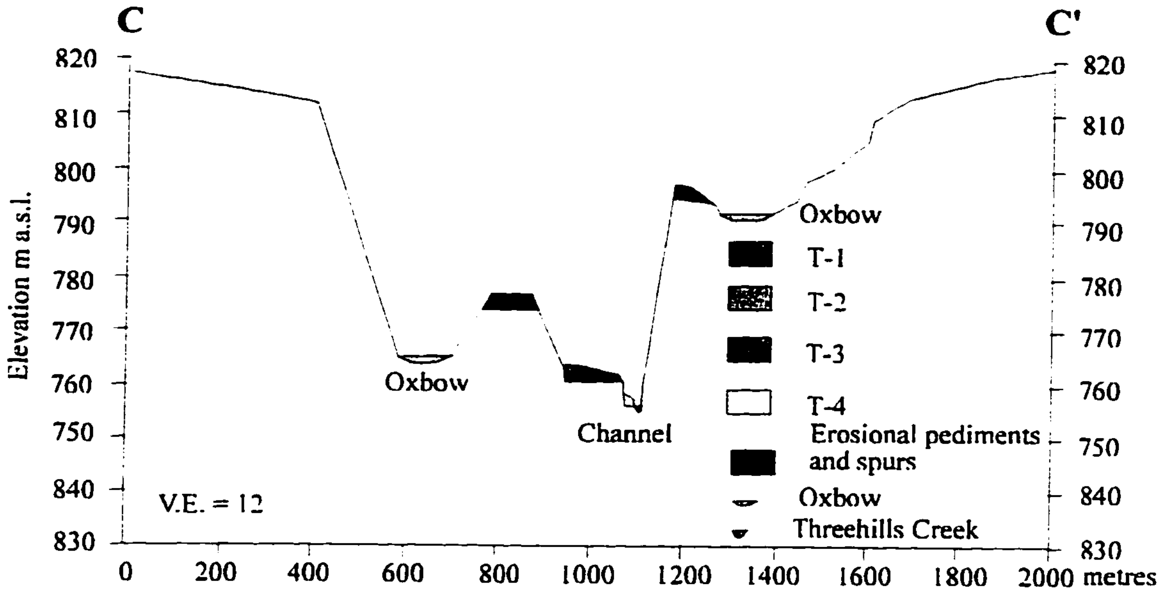


Figure 4.10.c Valley Cross-section C-C' (see Figure 4.3 for location)

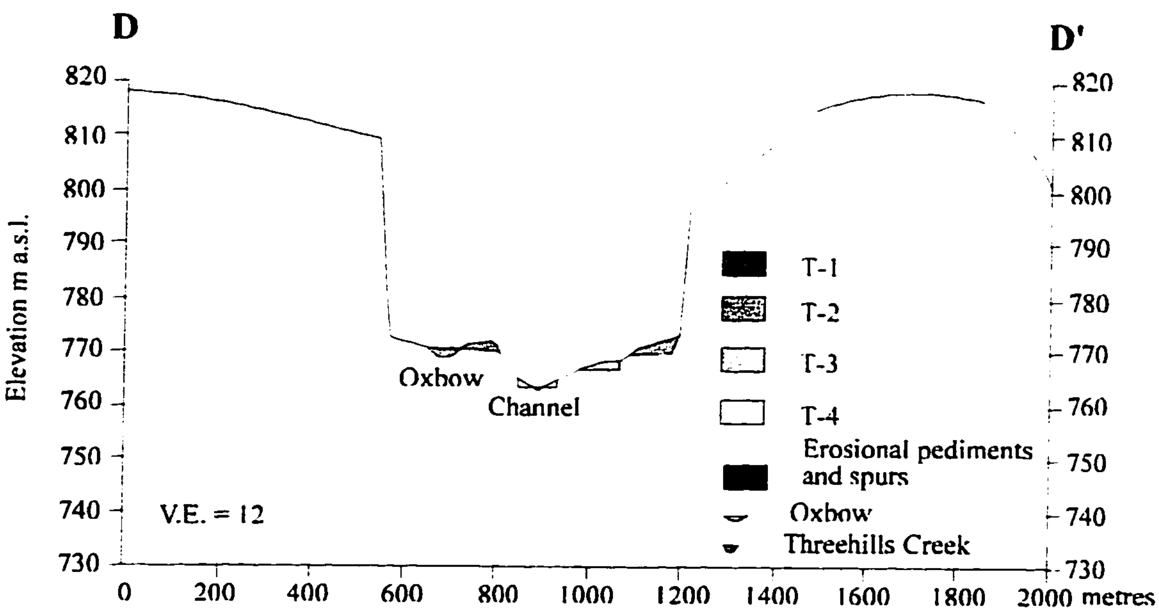


Figure 4.10.d Valley Cross-section D-D' (see Figure 4.4 for location)

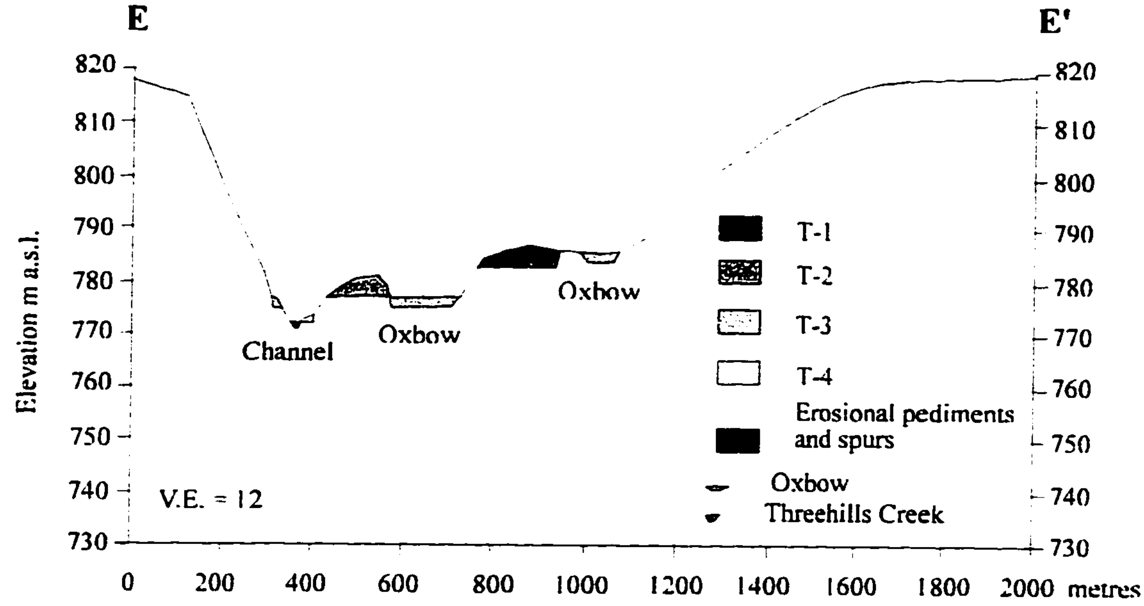


Figure 4.10.e Valley Cross-section E-E' (see Figure 4.4 for location)

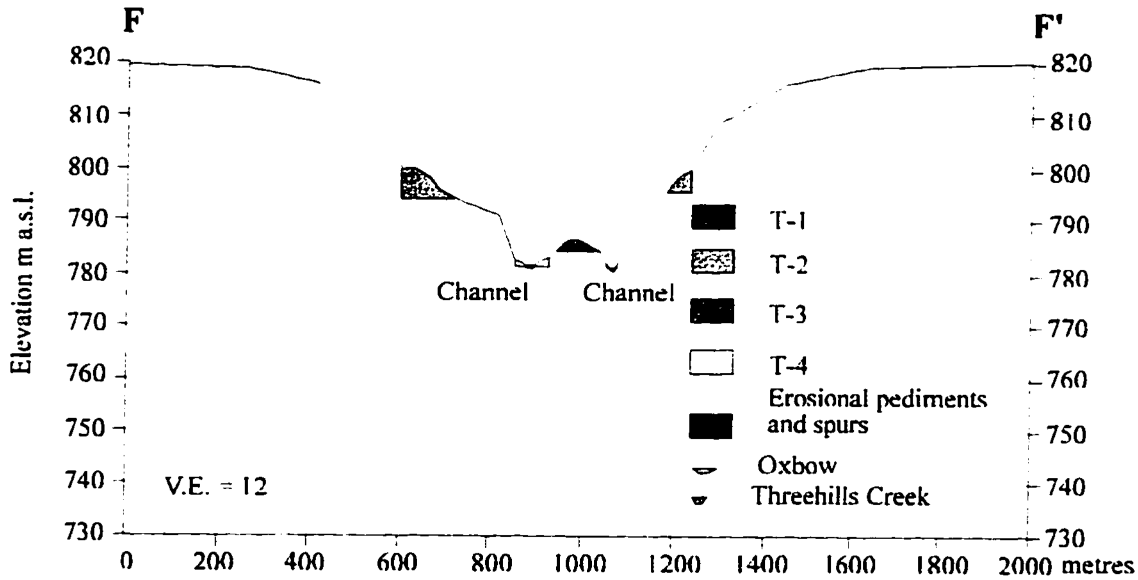


Figure 4.10.f Valley Cross-section F-F' (see Figure 4.4, 4.5 for location)

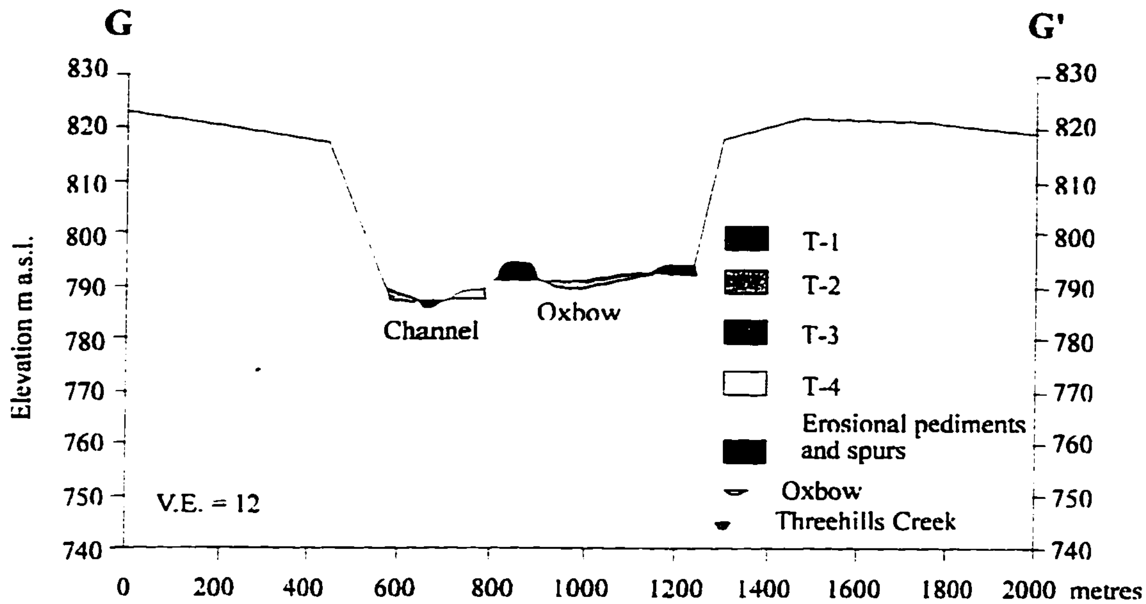


Figure 4.10.g Valley Cross-section G-G' (see Figure 4.5 for location)

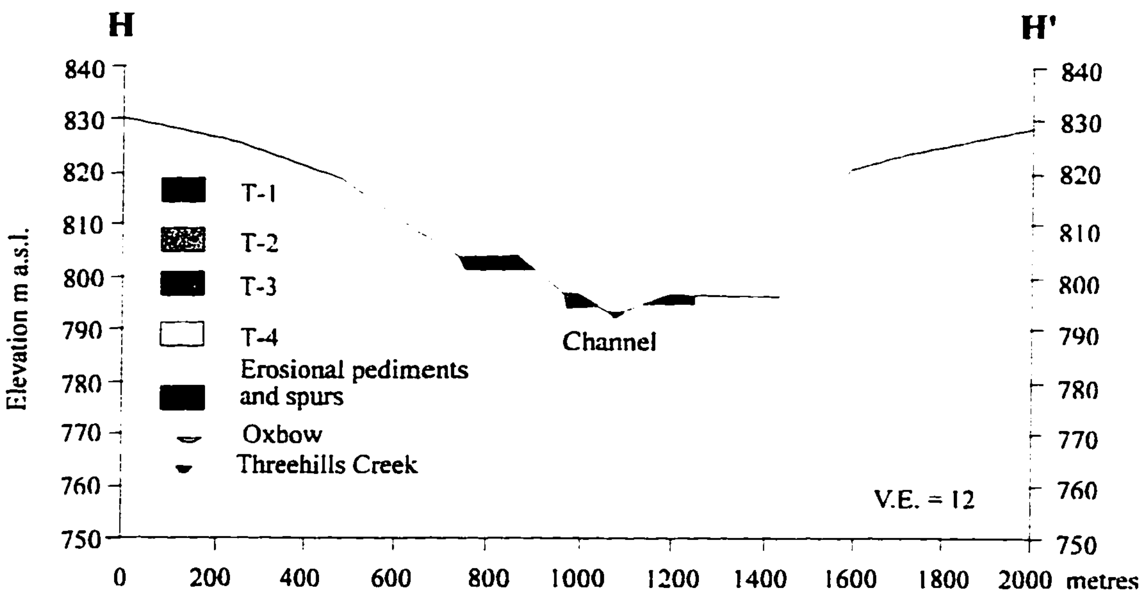


Figure 4.10.h Valley Cross-section H-H' (see Figure 4.5 for location)

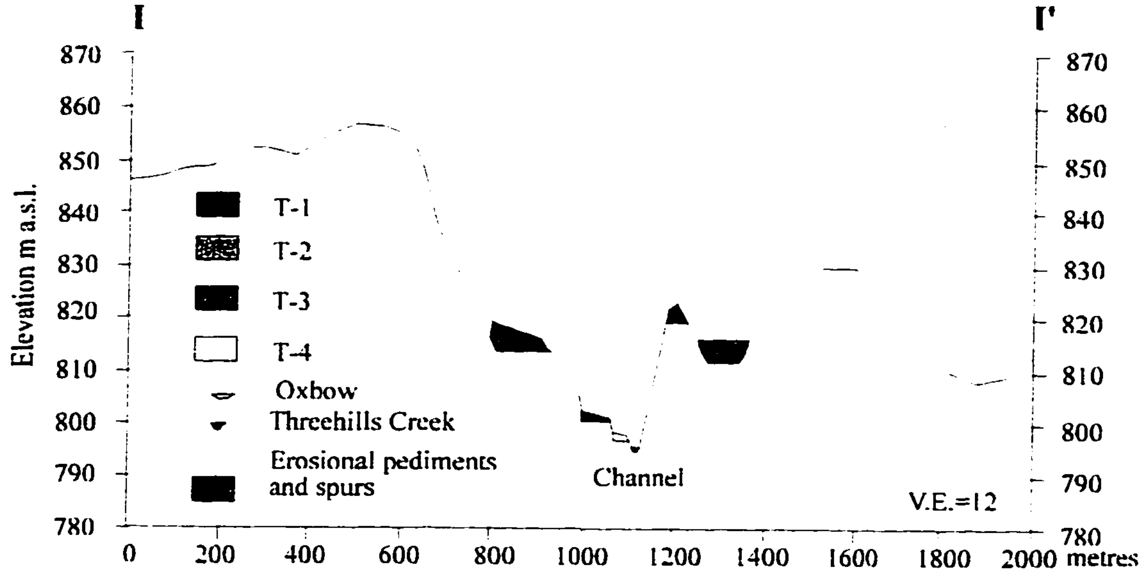


Figure 4.10.i Valley Cross-section I-I' (see Figure 4.6 for location)

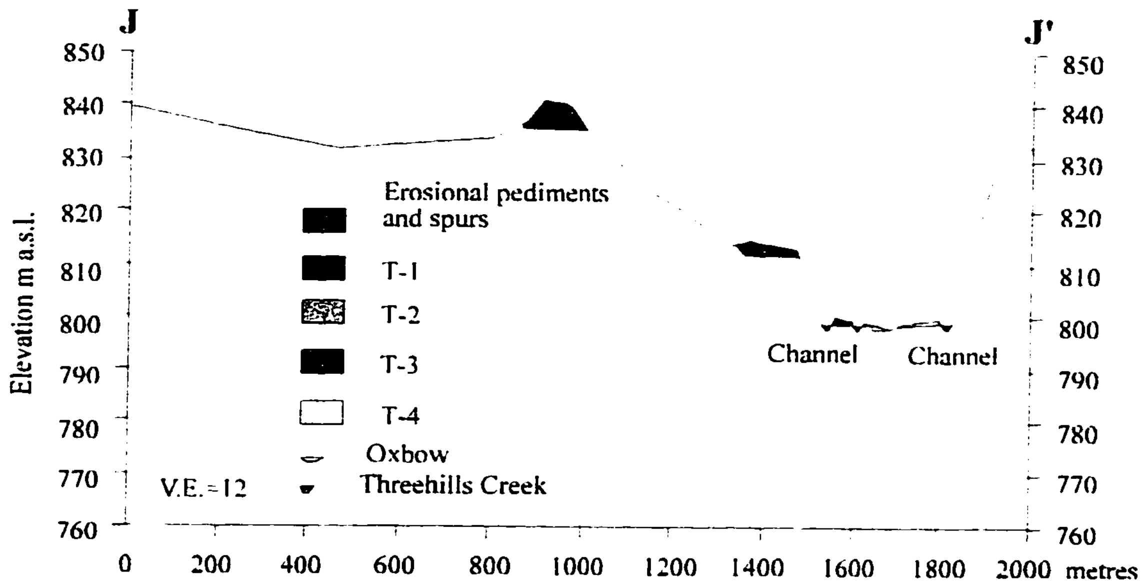


Figure 4.10.j Valley Cross-section J-J' (see Figure 4.6 for location)

J-J' (Figure 4.10.j) shows the more common valley development. with the wide movement of the early Threehills Creek. The erosional pediment that is equal in elevation to the valley walls was left behind as the creek incised, setting its path to the north. The steep, north, 25 m cliff still presents dramatic relief but from this point upstream the valley is mainly wide and shallow.

4.2.4 Representative Valley Terraces

Plates were chosen to best represent each terrace. A fifth plate (Figure 4.11), was chosen as it best presents three of the four terrace suites within Threehills Creek Valley.

The oldest terrace suite, T-1, has a limited number of exposures and restricted accessibility to them. The terrace chosen is 19 metres above the present channel. Figure 4.12 was taken at section 94 in a silage pit. This man-made exposure has a white band running horizontally through both sides of the pit about 2.3 metres from terrace tread. Upon closer inspection the white band was identified as tephra and upon analysis it was confirmed to be Mazama ash. The band was interbedded with a series of overbank deposits.

With the present creek incising into Section 4 of the T-2 suite, 11.32 m are exposed above the present channel (Figure 4.13). The bottom 4 metres of the section are covered with colluvium and 5 metres of bedrock are exposed above this. The majority of exposed bedrock consists of bentonite, the top metre is sandstone and is clearly visible in Figure 4.13.

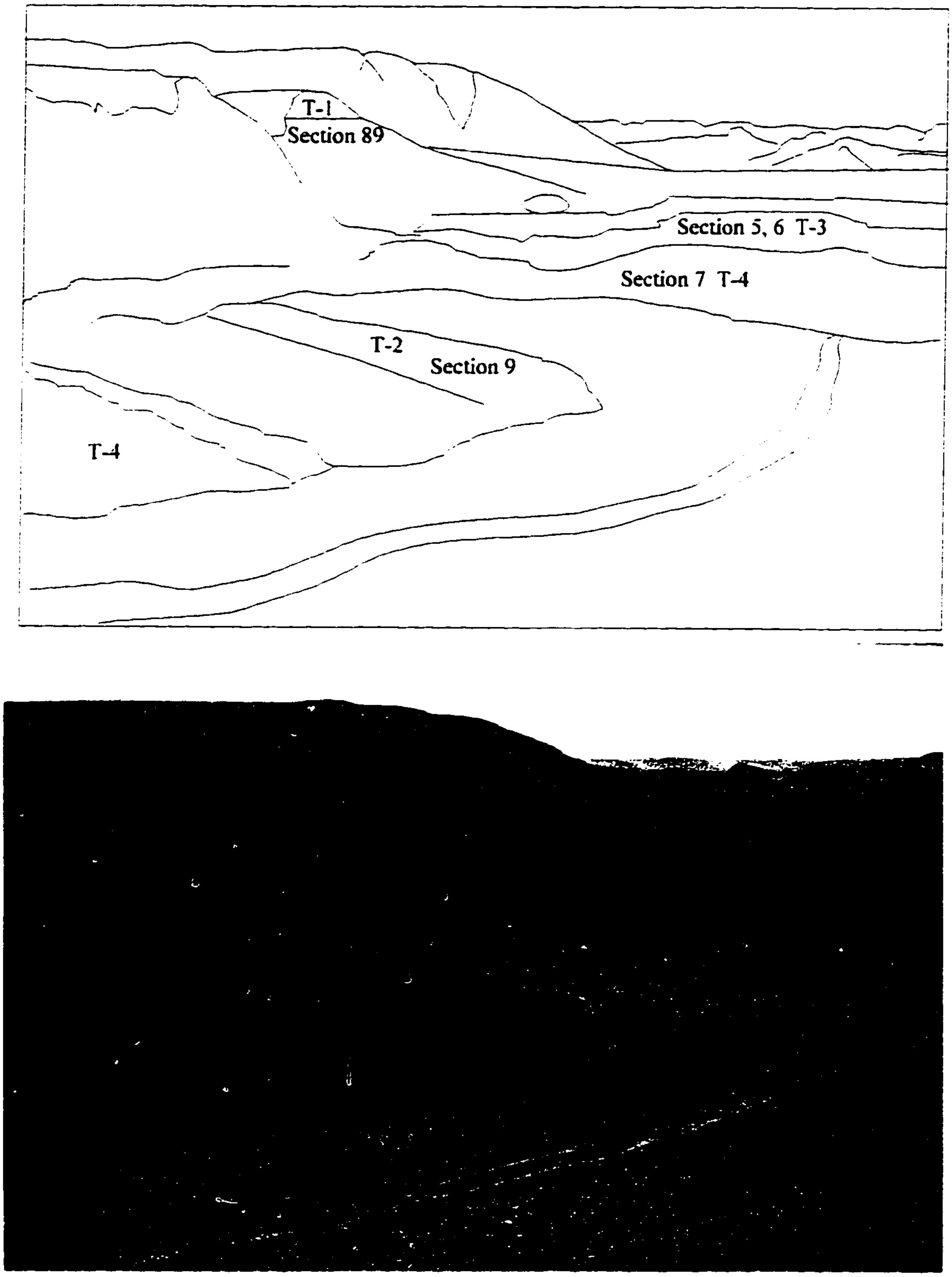


Figure 4.11 Composite showing T-1, T-2, T-3 and T-4 terraces

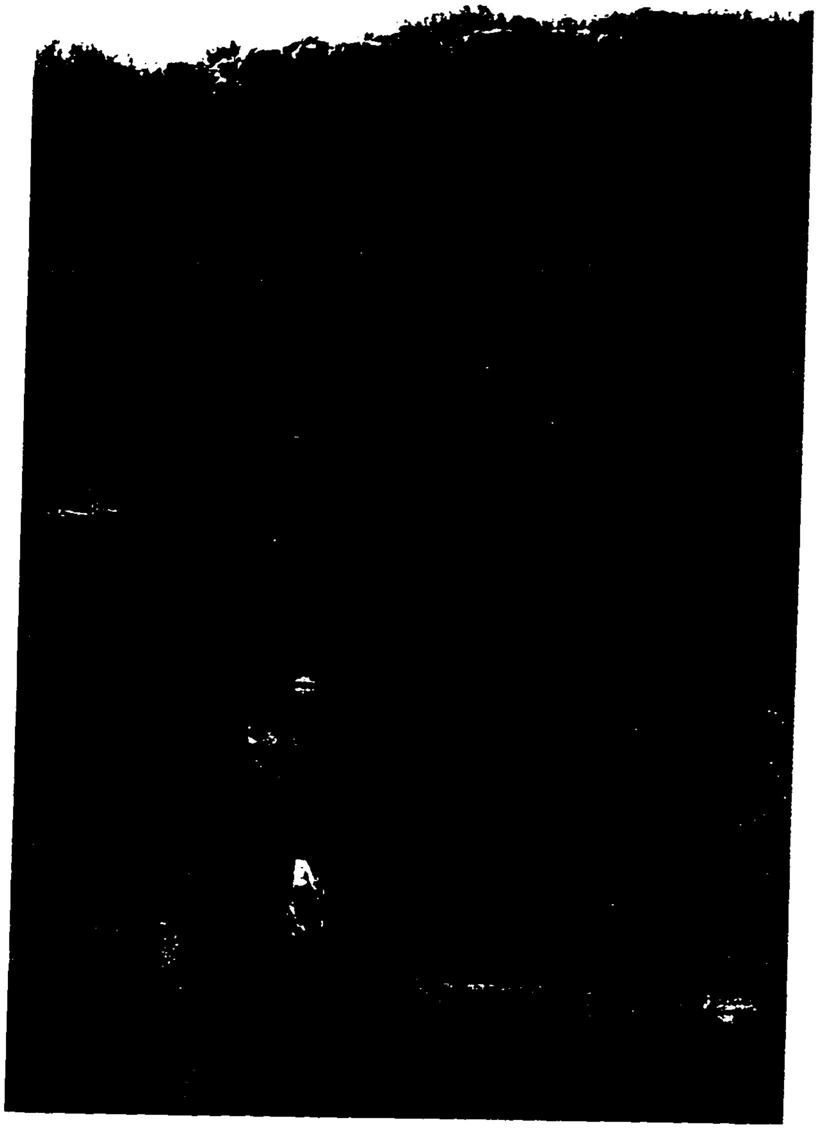


Figure 4.12 Section 94 representative of T-1 suite; note Mazama ash (white band).

Figure 4.13 Section 4 representative of T-2 suite

Figure 4.14 Section 11 representative of T-3 suite

Figure 4.15 Section 13 representative of T-4 suite

Above the sandstone lies a metre thick lens of stream rounded gravels. In these gravels a bone was also visible. Beside this gravel lens, sections of fining upwards point bar deposits were also evident. Massive overbank fines, 1.1 m thick, and made up of silt and clay, covered the gravels. Within these fines (at 0.3 m below the surface) a buried A horizon is evident. The modern prairie soil makes up the top 0.25 m.

Figure 4.14, section 11, represents the T-3 suite. This section is 8 metres above the current creek. The bottom third is covered with colluvium with well established vegetation near the base. Sandstone bedrock is visible approximately 2 m below the top of the section, at the height of field assistant Robin Thompson's head. Above the sandstone is 0.25 m of alluvial gravels followed by approximately 1.5 m of fine sand with two buried A soil horizons, one 0.62 m below the surface and the other 0.41 m below the surface. The uppermost buried A horizon is approximately 0.2 m thick. This exposure contained a large deposit of organic matter, corresponding to that of an oxbow. A bone was found 0.43 m below the surface just under the youngest buried A horizon.

Most T-4 sections are approximately 1 to 2 metres above the present channel with slumping or alluvium masking bedrock. Alluvial gravels are present from near the water surface to around the one metre level with some point-bar deposits to the 0.5 m mark and overbank fines from the 0.45 m mark to where the present A horizon is developing. Section 13 best represents this suite (Figure 4.15).

4.3 Alluvial Stratigraphy

4.3.1 Stratigraphic Sections and their Implications

The stratigraphic sections that were investigated and interpreted were all created as a direct result of fluvial action (Figures 4.16 - 4.23). Each section tells a different story with reference to the history of the creek. The sedimentary sequences are generalized as, from the bedrock up: (1) lag gravels armoring previous creek beds; (2) Point-bar deposits in the form of pebbles, sands, to silts and minor clays; and (3) overbank fines.

Rains and Welch (1988) pointed out that climate change probably was one of the major causes of terrace development in Strawberry, Weed and Whitemud creeks. With a similar base level, sediment source and tectonic stability as these prairie creeks entering the North Saskatchewan River, the Threehills Creek terrace development can be linked to climate shifts as well.

During a period of stability within a channel system finer sediments that are easily transported are removed by the stream. In this manner gravels, cobbles and boulders soon dominate the stream bed. In Threehills Creek these lag gravels were predominantely of local bedrock (Paskapoo Formation sandstone and Horseshoe Canyon Formation sandstone) and with lesser amounts of reworked shield granite erratics. As the stream bed becomes armored with lag gravels and the depth of this gravel thickens there is a direct effect upon the stream. It responds by cutting laterally, eroding preferentially into the floodplain rather than incising into coarser-grained lag gravels. Bed armoring is known to cause lateral movement and inhibit incision (Rains 1969, Rains and Welch 1988). In an exposure, the lateral movement of the creek may be partly shown by the imbrication of lag gravels as the stream shifted. A terrace tread more often shows elevation mirroring the lateral movement resulting from bank erosion. During periods of stability within a system the stream responds by moving laterally with alluvial gravel and finer deposits accreting and little or no incision into the valley bedrock (Schumm 1993).

Due to the meandering nature of Threehills Creek, lag gravels over bedrock were visible in most terrace sections. except for T-4 where colluvium generally covered the contact between bedrock and alluvium. In the terraces, deposition of lag gravels was by lateral accretion similar to that described by Stene (1980) at Trout Creek. Porcupine Hills, Alberta.

Point bars are developed in the lower energy section of a stream such as the inside of a meander. Slowly accreting. the point bar grows as the energy of the stream decreases. releasing mainly bedload sediment. The point bars were generally made up of fine gravel and coarse sand. These sands and gravels would have been predominantely a result of fluvial action reworking larger lag gravels and bedrock. The common trough between the point bar and slip off slope creates an even lower-energy zone, infilling with finer alluvial material such as silts and clays. The low energy of Threehills Creek created poor compaction within most of the point bars. Close inspection of point bar deposits commonly showed the fining upward sequences that are typical of this fluvial form. This characteristic point bar sequence could be distinguished in the larger sections when viewed at a distance.

For terrace development a constant source of fine sediment is necessary. These sediments are predominately from the basin and arrive in varying manners and, because they are deposited in the channel and on the floodplain. their origin is of special interest.

Fine sediments derive from sheetwash on slopes; from fluvial action of the creek mechanically breaking larger cobbles and gravels; and, from aeolian sediment directly or trapped in snow and transported to the creek during spring melt. During a drought, or soon after a prairie fire, vegetation cover is sparse allowing soil to be washed into the channel during heavy downpours (Stene 1980). This sediment does not necessarily enter the channel immediately but becomes concentrated in significant volumes along the floodplain and is transported during overbank conditions or is eroded during normal lateral migration of the stream.

Every spring, floods both deliver and remove sediment from the system. As long as the energy of the stream is high enough, sand, silt and clay are held in suspension and moved through the system. As the discharge decreases only finer sediments are removed in suspension until the water clears. Overbank fines are dominated by fine sediments, silts and clays, that are easily carried in suspension. Though gravels may also be deposited along with overbank fines. Stene (1980 p. 317) noted, "poorly sorted gravel within the fine-grained terrace alluvium" of wide valley cross-sections along Trout Creek. Both wide valley cross-sections and gravel in overbank fines are found in Threehills Creek overbank alluvium. Though within measured sections the significant gravel deposits are predominately lag gravels or gravels in point-bar lower sequences, overbank deposition documented mainly fine gravels to coarse sand.

There are two types of overbank deposition, lateral and vertical accretion. A fining upward of sediment is found in both these types of deposition. However, in the absence of lamination, bedding or fining upwards sediment is described massive. Many of the stratigraphic

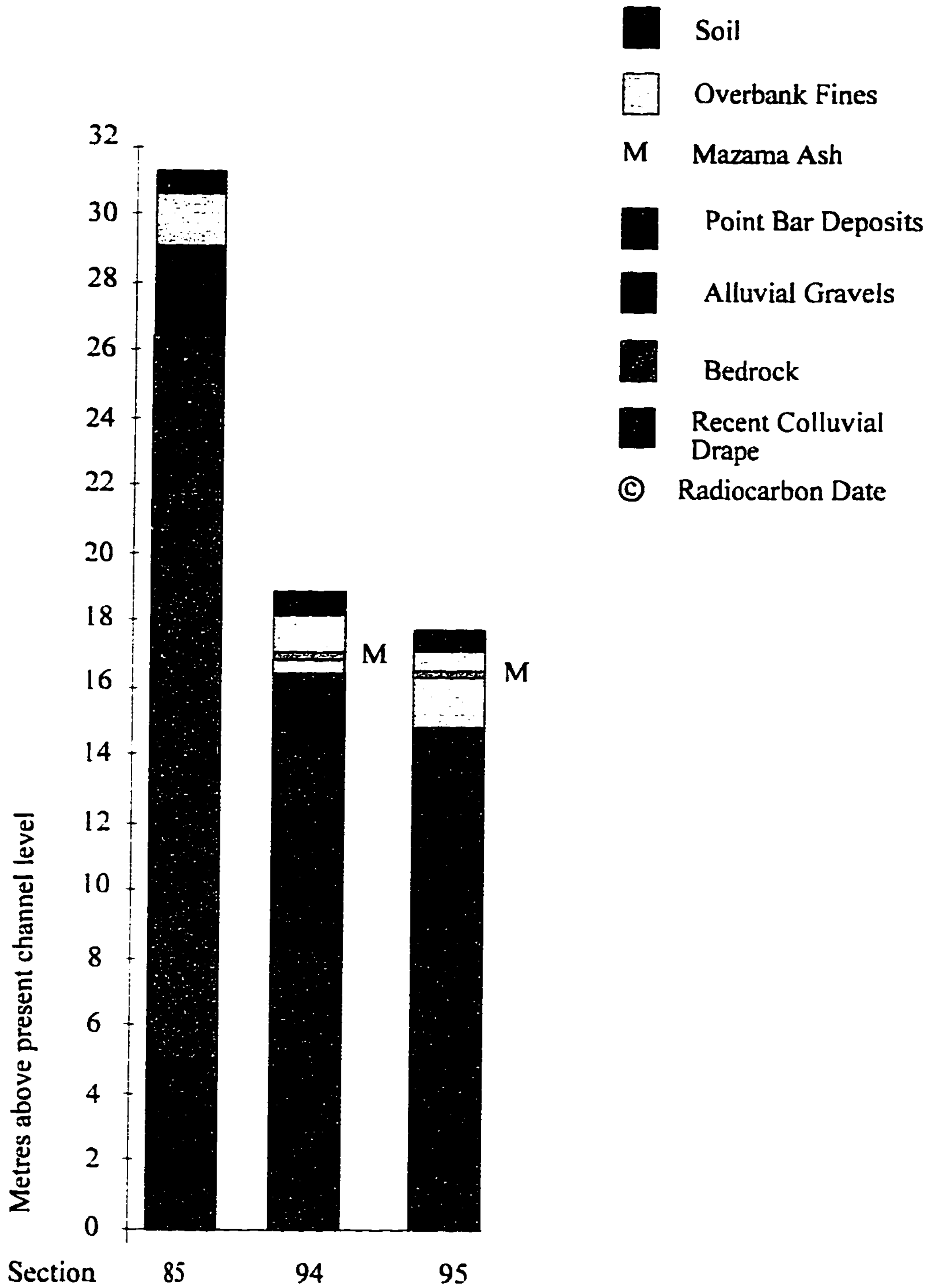


Figure 4.16 Threehills Creek, Terrace One Sections

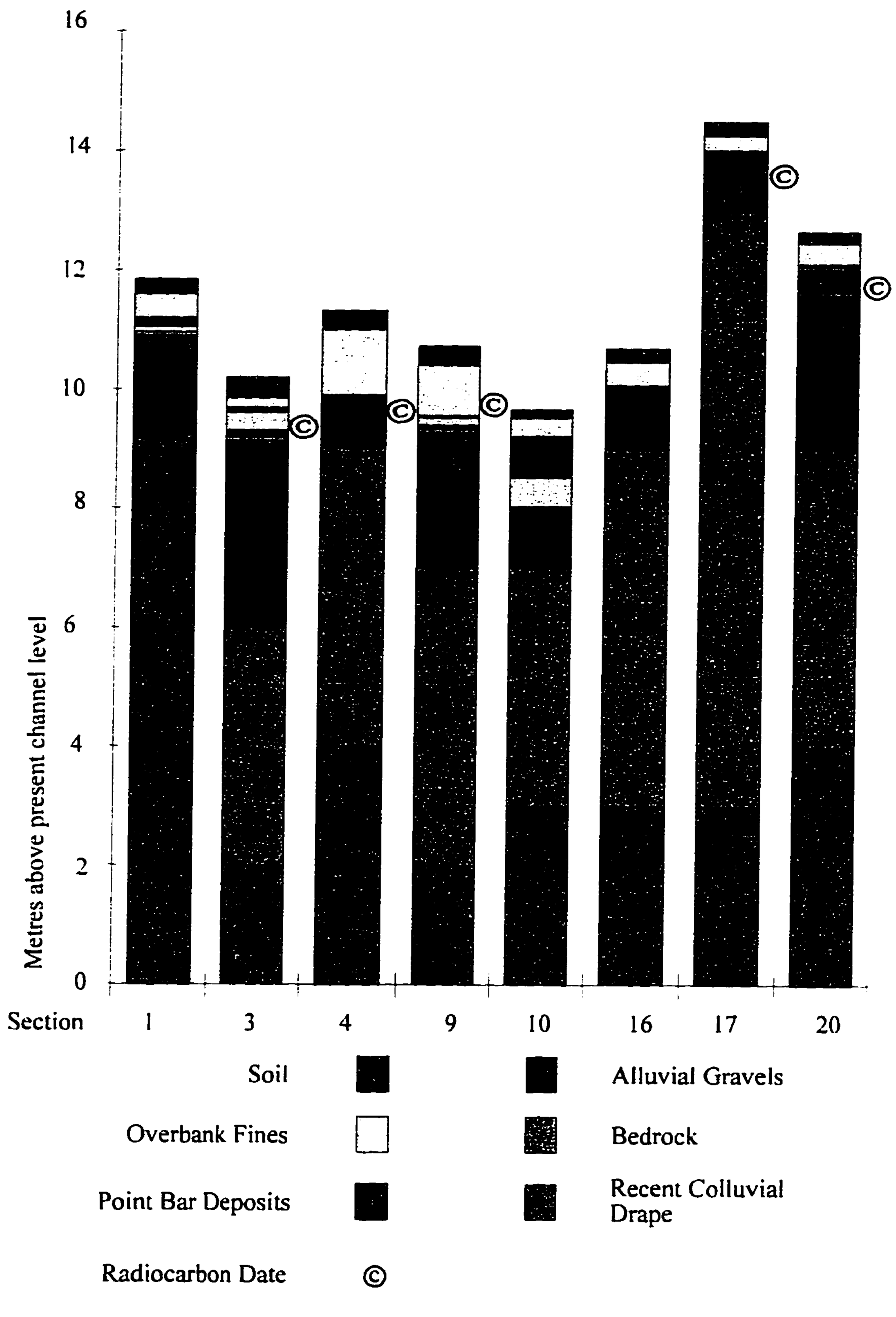


Figure 4.17 Threehills Creek Terrace Two Sections

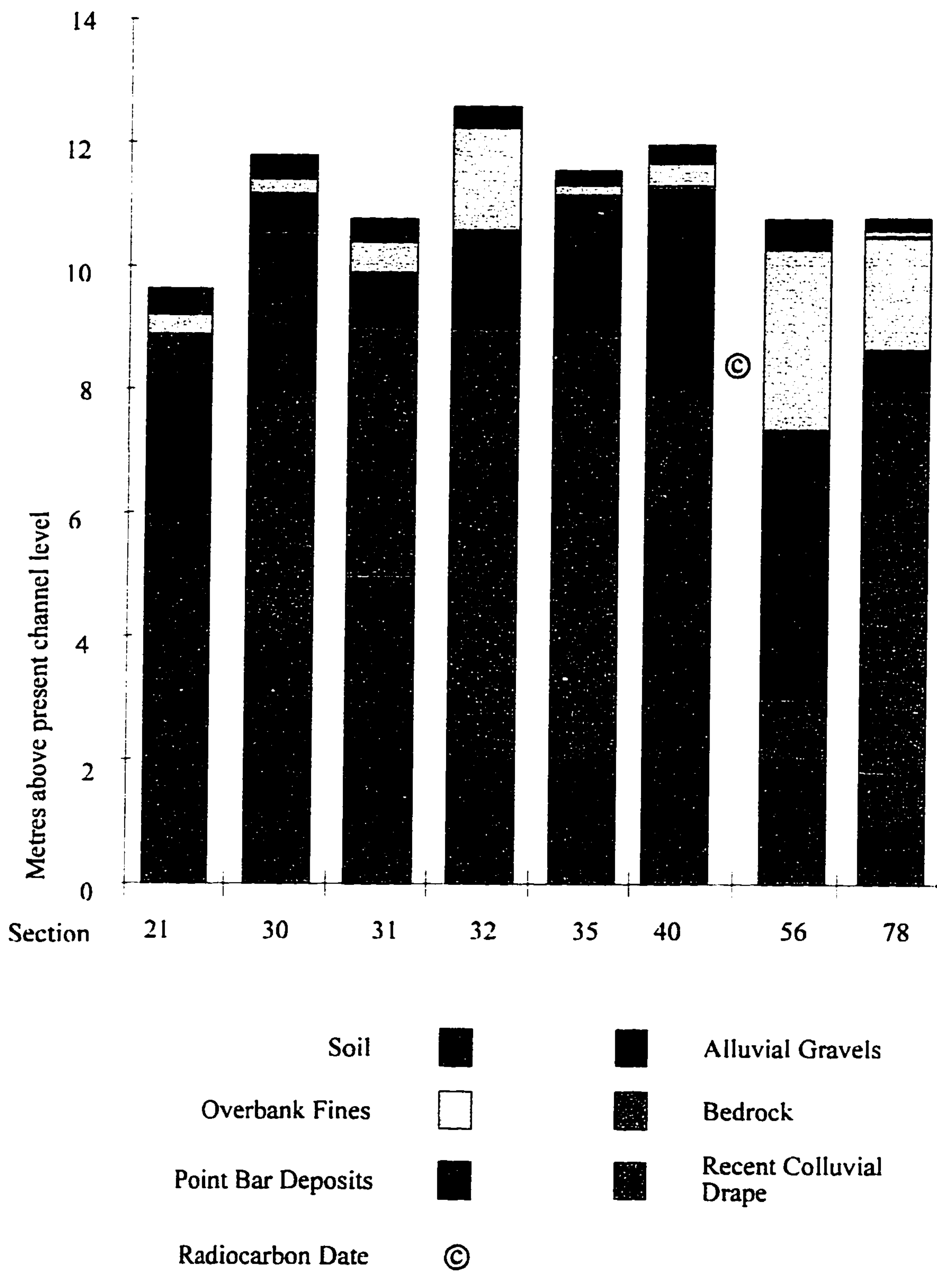


Figure 4.18 Threehills Creek Terrace Two Sections

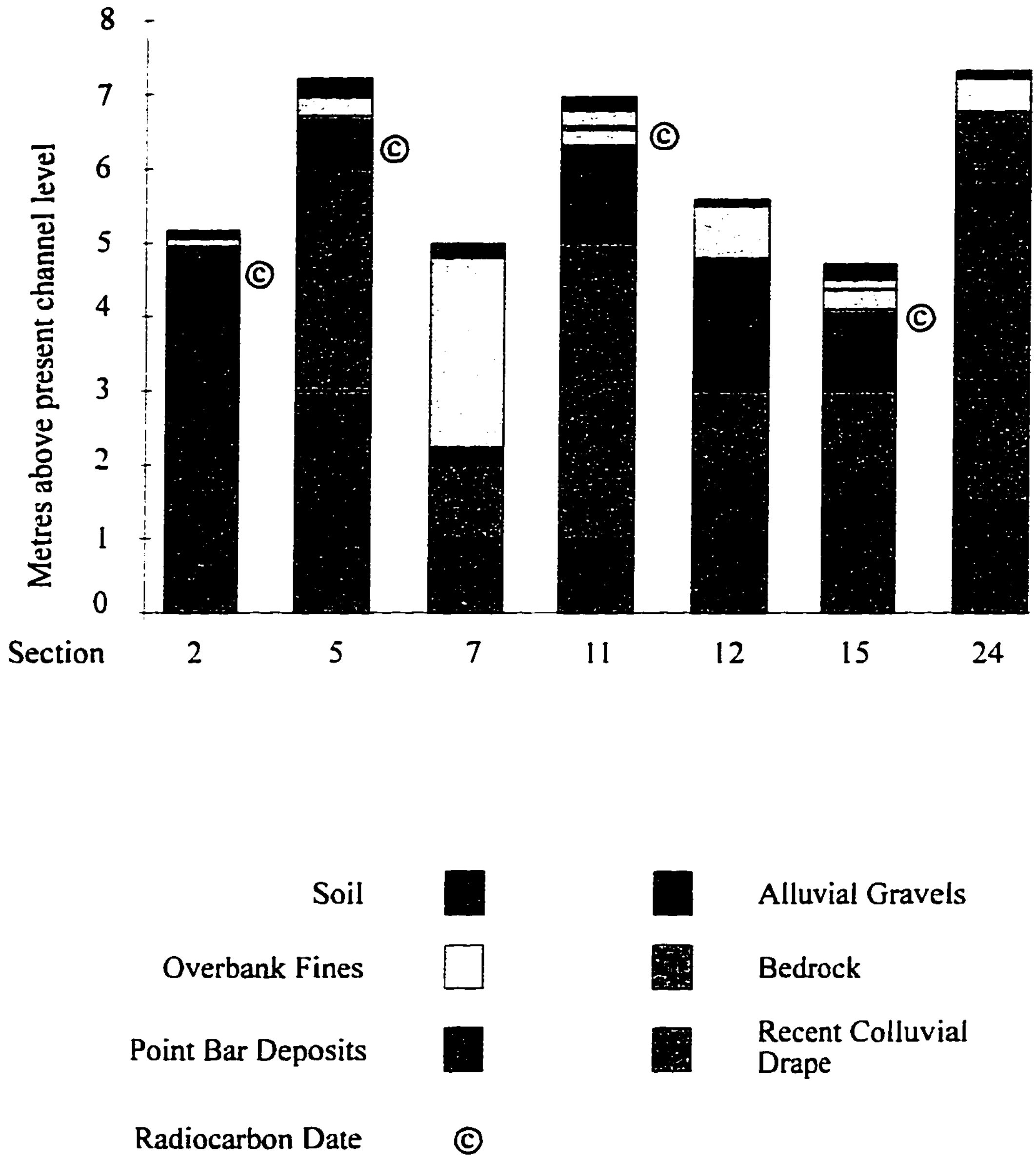


Figure 4.19 Threehills Creek, Terrace Three Sections

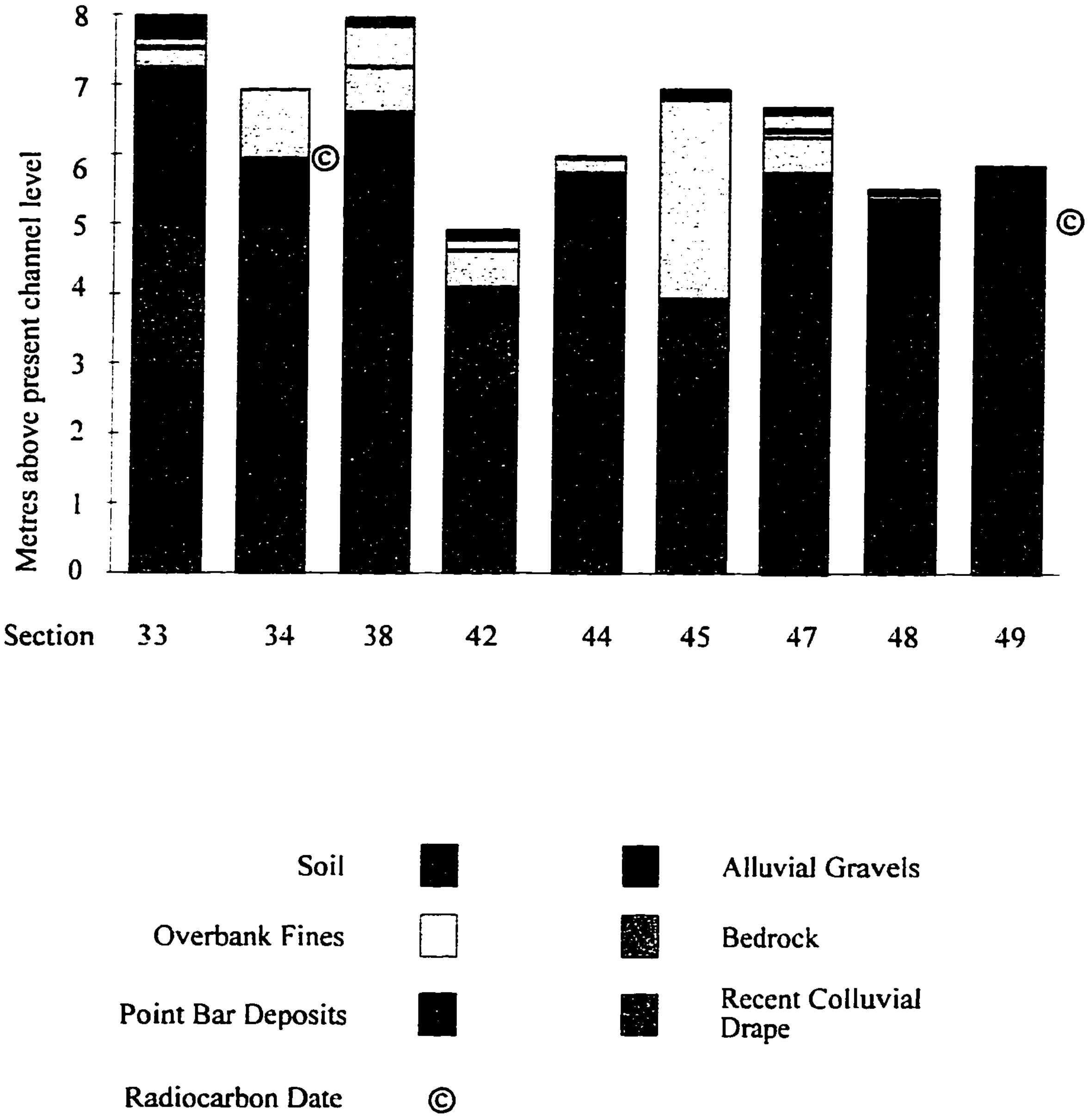


Figure 4.20 Threehills Creek, Terrace Three Sections

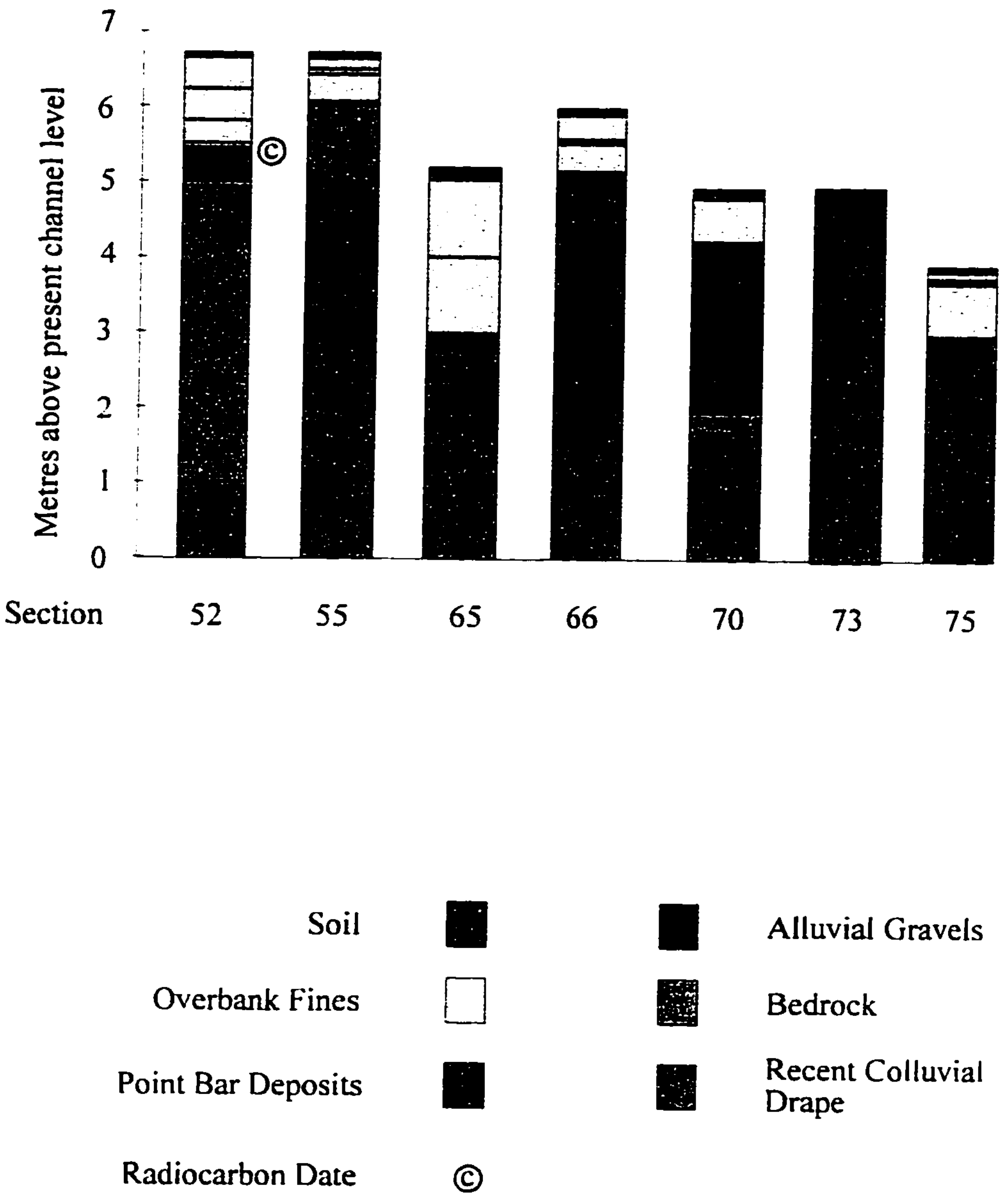


Figure 4.21 Threehills Creek, Terrace Three Sections

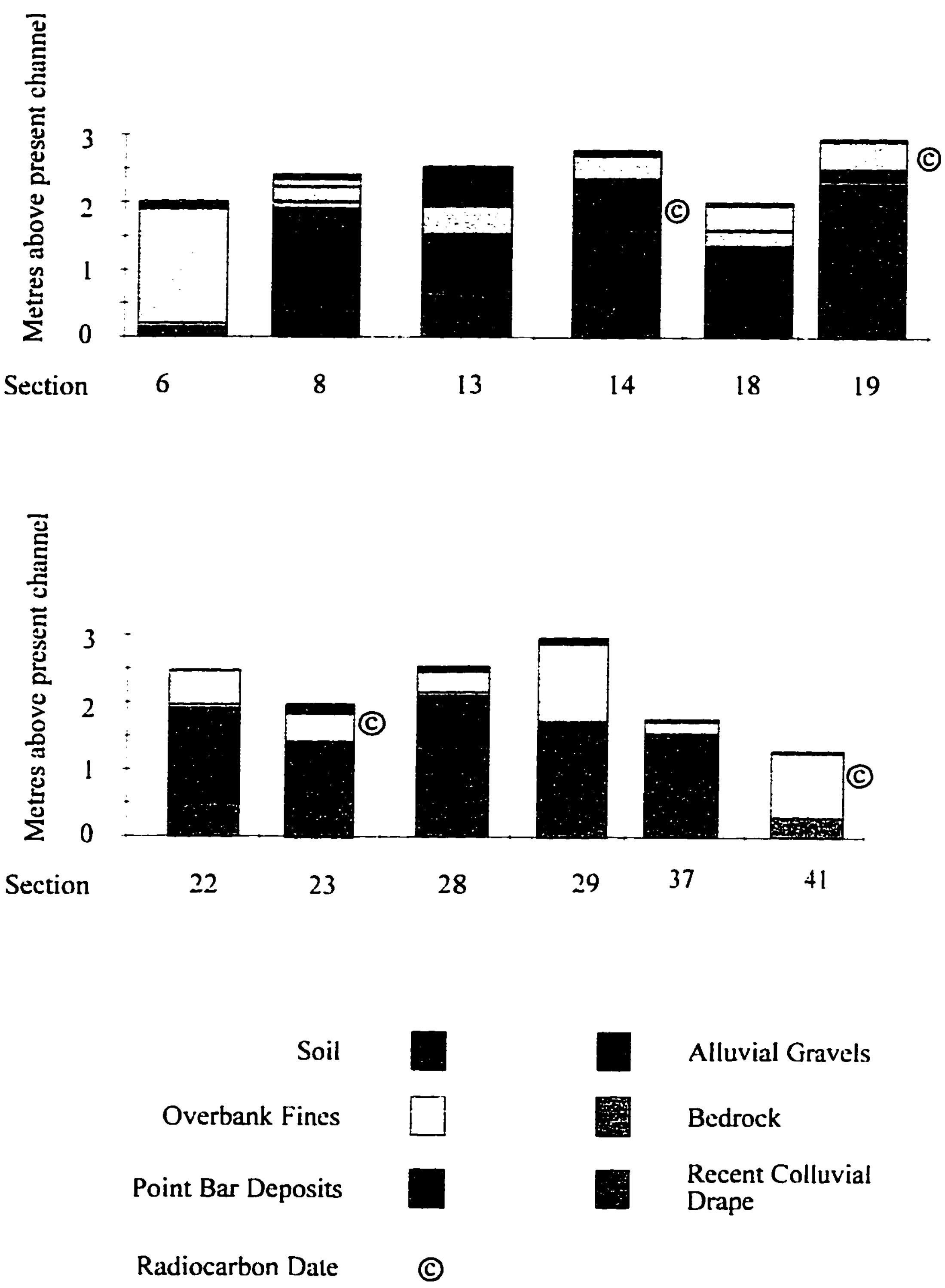


Figure 4.22 Threehills Creek Terrace Four Sections

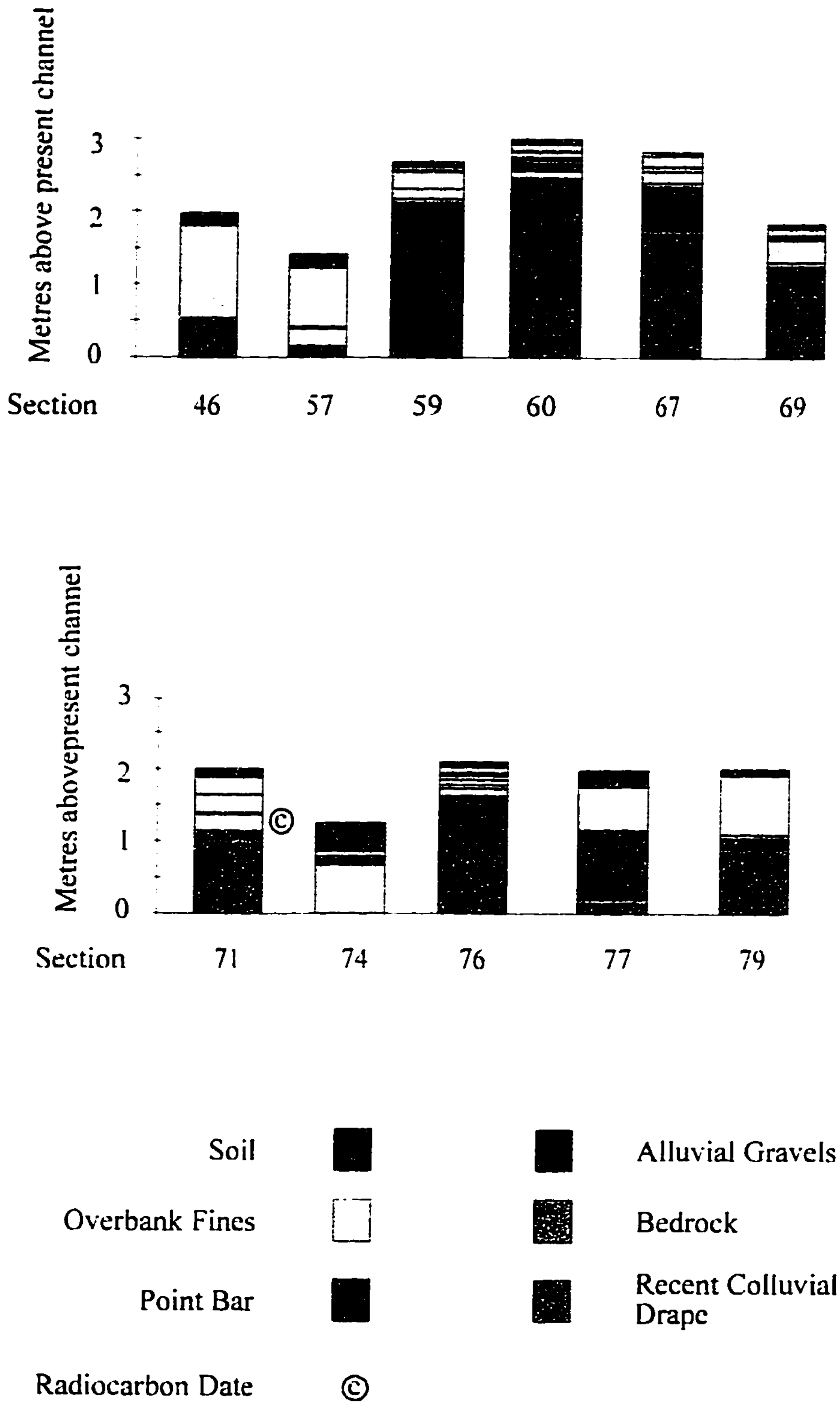


Figure 4.23 Threehills Creek, Terrace Four Sections

terraces of Threehills Creek showed this massive character in the overbank fines.

In the section of the creek studied, paired terraces within the Threehills Valley developed with lag gravels, laterally accreting. Point bar deposition added to the terrace sequence as the creek moved across the floodplain. Upstream, fine sediments accumulated in the lower energy stream and on the floodplains. When flood conditions were strong enough to erode these sediments and carry them in suspension, they were easily transportable by the stream. These silts and clays were then redeposited upon the floodplains of downstream portions of the creek. If the system is stable and the floodplain has reached a certain height the only method of it aggrading is from overbank deposition. As the floodplain continues to build in height, when the stream is in flood, overbank deposition occurs, but higher stage floods are then necessary achieve further overbank flooding. Smaller and finer layers of overbank fines occur with seasonal floods as longer durations between overbank floods ensue. These episodes in which the terraces accrete can range from decades to centuries as represented by developed paleosols (Stene 1980). It appears that overbank deposition is increasingly rare in the final stage of a terrace's development, and that for the next geomorphic phase to commence a control, such as a climatic shift is necessary to upset the balance.

4.4 Chronology of Valley Development

4.4.1 Objective

A chronological framework for the terrace development has been reconstructed on the basis of numerous radiocarbon dates and the identification of Mazama ash in two sections of Threehills Creek T-1 alluvium (Table 4.1, Figures 4.24.a, and 4.26).

Relative abundance of FeO, CaO and K_2O in glass of some widespread Quaternary tephra layers in western North America is shown by Table 4.1 and Figure 4.26. All determinations were done on an electron microprobe. Compositional range is based on 43 samples in the case of Mazama (M) tephra, 21 for Bridge River (B.R.) tephra, 15 for St. Helens(S.H.) set Y tephra, 16 for Pearlette (P) tephra and 18 samples for the Bishop Tuff (B.T.). The Bishop Tuff data, and some of those for Pearlette tephra come from Izett et al. (1970) the remainder is the work of Westgate (1977).

All the radiocarbon dated material was bison bone. Though a deer rib was found, it did not yield sufficient collagen to be used for dating. In all, 27 samples were collected, with 18 yielding sufficient collagen to be radiocarbon dated.

4.4.2. Initial Incision

It appears that following deglaciation and drainage of the glacial ponds Threehills and Ghostpine, the initial, postglacial Threehills Creek began incision by meandering over a much larger area than it occupies today. The absence of any dated material prior to Mazama ash leaves it to speculation as to when stability was first reached in the system. The only other available dates are (Rains and Welch 1988) from two Strawberry Creek T-1 (Figure 4.25b) remnants dated by charcoal at 8660 $\pm$ 125 yrs B.P. (S-1926) and a bivalve mollusc at 8015 $\pm$ 135 yrs B.P. (S-1787). As these dates appear reasonable and would fit into the time sequence of

Table 4.1 Average glass composition (wt. %) of Mazama ash.

Mineral	Average Mazama ash	Threehills Creek T-1 tephra	Kneehills Creek T-1 tephra	Strawberry Creek T-1 tephra
SiO_2	72.27±.65	72.4	72.45	73.22
TiO_2	0.49±0.02	0.41	0.45	0.42
Al_2O_3	14.85±.17	13.96	14.24	14.34
*FeO	2.02±.05	1.93	2.08	2.14
MnO	0.04±.01	0.05	0.05	0.05
MgO	0.53±.03	2.8	3.18	5.54
*CaO	1.61±.04	1.63	1.74	1.34
Na_2O	5.23±.16	2.8	3.18	5.54
*K_2O	2.67±.04	2.28	2.62	2.71

See Smith and Westgate (1969)

See Rains and Welch (1988)

*Index minerals

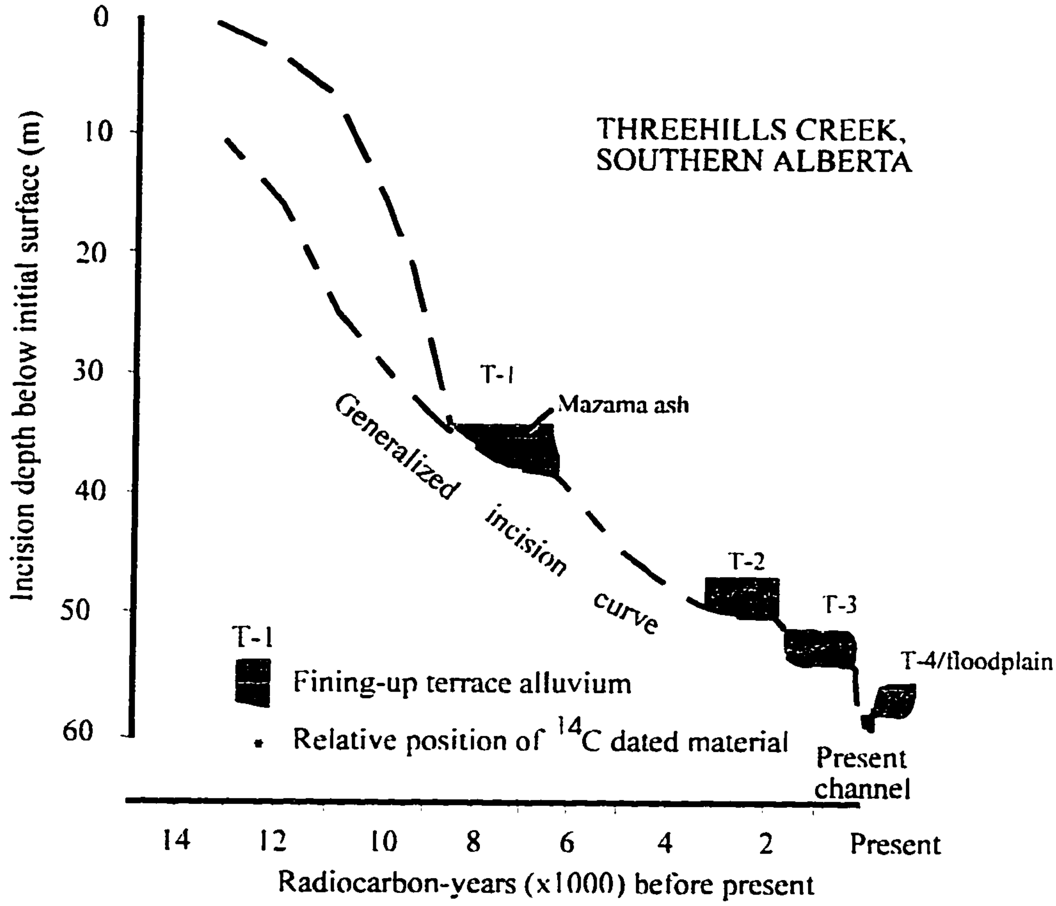


Figure 4.24.a Threehills Creek incison curve (Rains upublished)

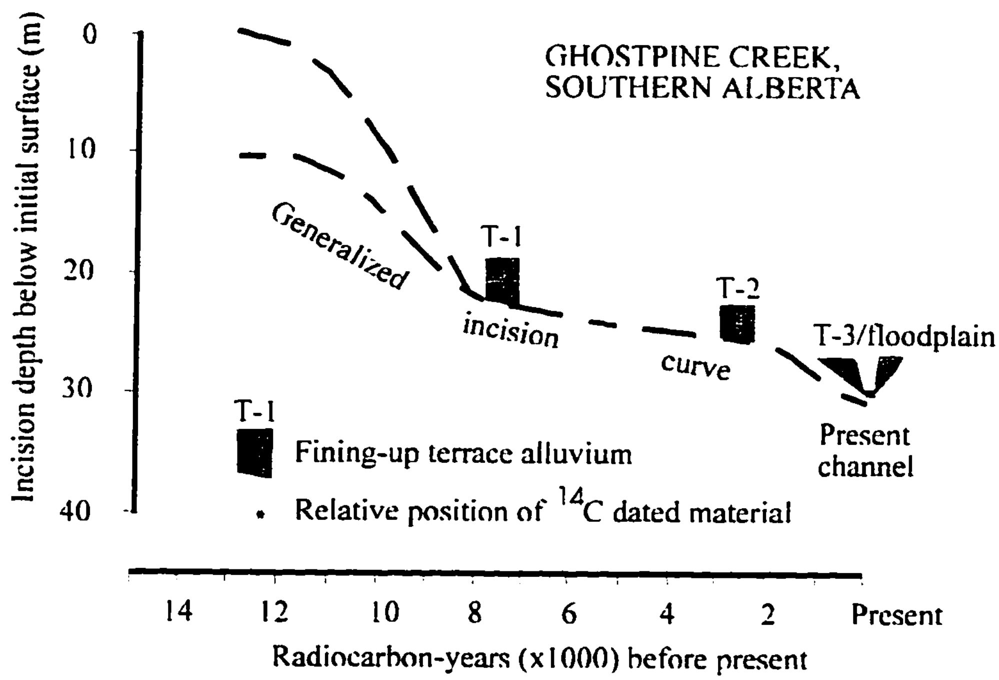


Figure 4.24.b Threehills Creek incison curve (Rains upublished)

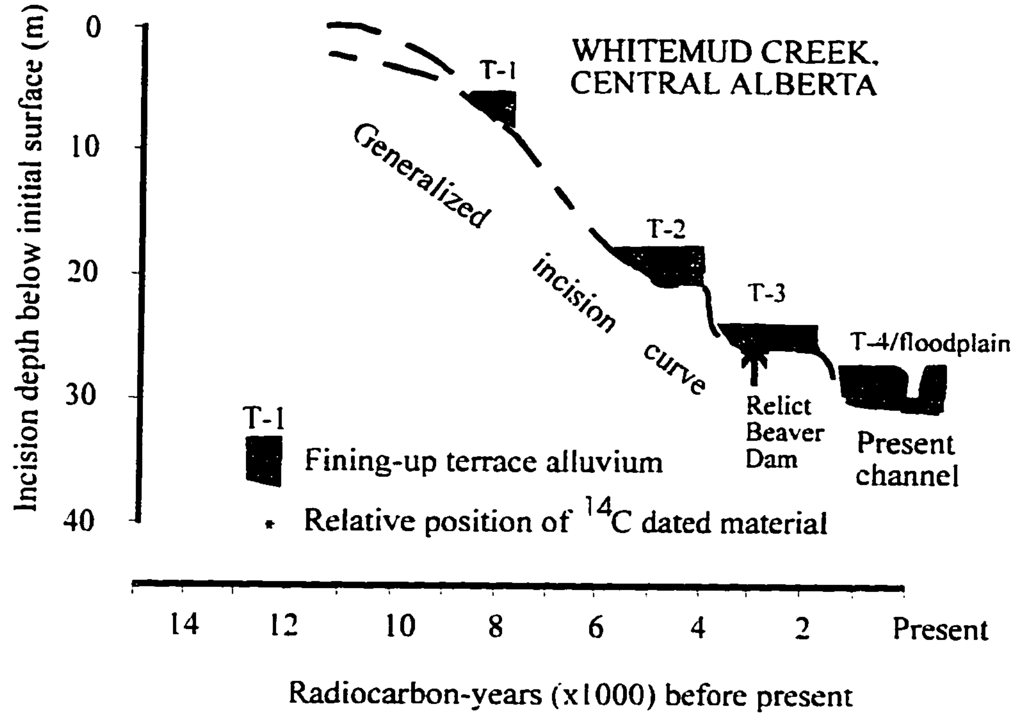


Figure 4.25.a Whitemud Creek incision curve (Rains unpublished)

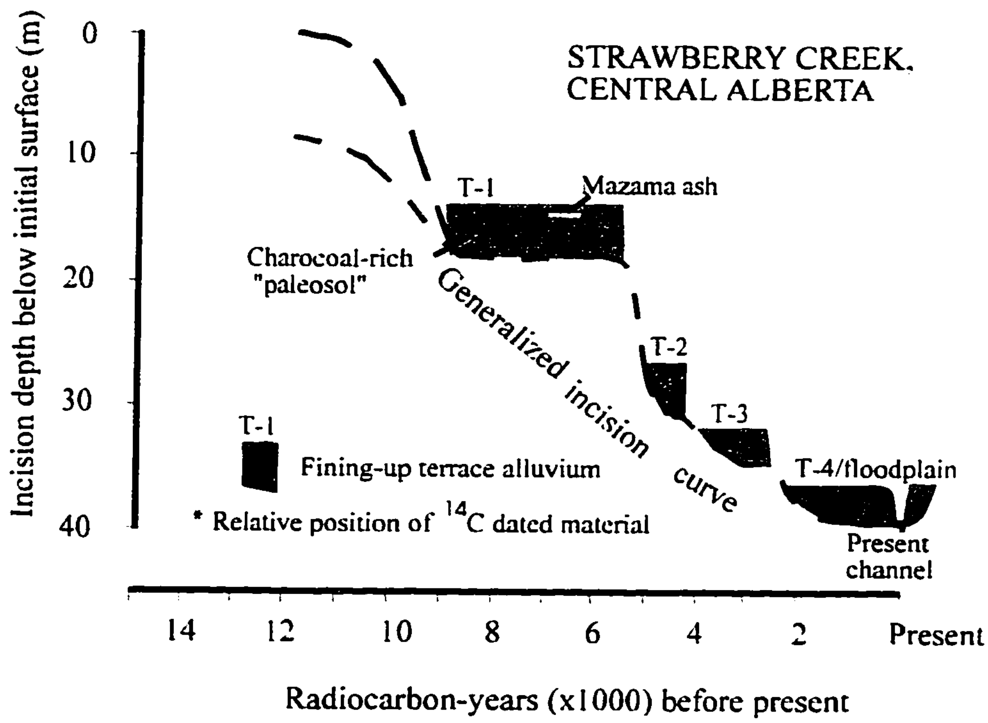
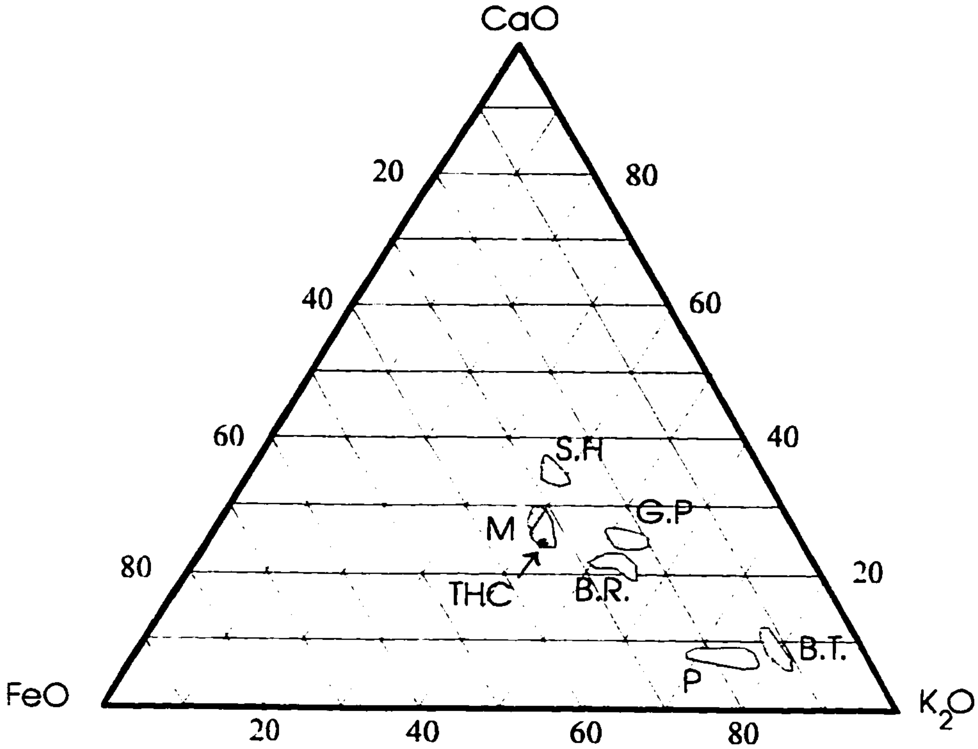


Figure 4.25.b Strawberry Creek incision curve (Rains unpublished)



S.H. St. Helens Tephra
G.P. Glacier Peak
B.R. Bridge River
B.T. Bishop Tuff
P. Pearlette
M. Mazama
THC Threehills Creek

Figure 4.26 Mineralogical signature of Threehills Creek tephra.

Ternary diagram based on Westgate and Briggs (1980)

Threehills Creek it will be assumed until further evidence appears that the creek reached stability at ~8700 yrs B.P.

The terrace remnant containing section 85 (Figures 4.3, 4.10.c), contained no visible Mazama ash in its exposure. This can be interpreted as either the terrace was formed: prior to Mazama ash deposition; after Mazama ash deposition; or Mazama ash was eroded away prior to being incorporated within the terrace sequence. The valley rim surface at this point was 820 m a.s.l. The top of the terrace remnant lies at 786 m a.s.l. and the paleochannel at 780 m a.s.l. This would indicate that after the drainage of Glacial Pond Threehills the stream incised ~34 m prior to the first stage of aggradation (Figure 4.23.a. In this diagram note; the two initial valley rim elevations, the lower elevation was taken upstream near T-1, sections 94 and 95, the end of the study area and the higher elevation was taken downstream near T-1, section 85, the beginning of the study area) or ~1.4 m/100 years. When compared to the initial incision of creeks such as Whitemud and Strawberry, (5 m and 15 m, Figures 4.24.a and b, respectively) and Ghostpine (18 m, Figure 4.23.b), this initial incision is substantial.

4.4.3 Phase 1 (T-1)

Initially Threehills Creek incised for a significant period of time to isolate the terrace remnant where section 85 (Figures 4.3 and 4.10c) was measured. Isolated by a paleochannel, section 85 of the T-1 alluvial suite is 31 m above the current channel and 35 m below the valley rim. The bedrock of the section is topped with 1 m of gravels, 1.3 m of point bar fines, overbank fines and a well developed soil. No datable material was found in this exposure.

Section 94 (Figures 4.6, 4.11.b and 4.14) is in a silage pit incised into a T-1 terrace remnant along the valley wall. The pit exposed ~4 m of alluvium, colluvium from the silage pit covered any bedrock exposures. About 60 cm of lag gravels were exposed above the colluvium and a metre of fines above that. It is unclear whether they are point bar sediments or overbank deposits. A buried paleosol was identified at 2.3 m below the tread surface and a well defined layer of tephra just above it. Above the tephra lay 2.2 m of overbank fines to the surface where a well defined, 20 cm thick A horizon of modern soil has developed.

Section 95 also contains a layer of tephra, and due to the close proximity and similar elevation it is assumed to be the same tephra. A sample was taken from section 94 and electron microprobe analysis was used to compare it with tephra analysed by Westgate et al. (1980). This comparison confirmed it to be Mazama ash.

Sections 94 and 95 are in a paired set of terraces separated by the present channel. The terrace heights of 19 m and 17.6 m, respectively, above the present channel correspond closely. The slight elevational difference of 1.4 m between the two can be easily explained by the proximity of Section 94 to the valley wall and the continual addition of colluvium to the terrace surface. The colluvium is not easily differentiated from overbank deposits.

The two upstream T-1 sections (94 and 95) are 18 and 17 m, closer in elevation to the present channel than the downstream section 85. Figure 4.24 notes these local differences in initial valley rim elevations. Using the terraces along the valley wall that were measured and mapped from DEMs, longitudinal profiles, including the proposed T-1 terrace profile, were created (Figure 4.8). The T-1 longitudinal profile shows the divergence of the T-1 profile from the present-day, longitudinal channel profile.

The similar height of both terraces would indicate that they were forming at the time of deposition of Mazama ash upon the terrace tread. Soon after 6800 yrs B.P., overbank deposition buried the layer, preserving the tephra. It is difficult to determine whether section 85 was not in a good position to collect and preserve Mazama ash within its stratigraphy or whether the terrace had been formed and isolated prior to Mazama ash deposition.

4.4.4 Phase 2 (T-2)

Six dates were obtained from radiocarbon datable material found in the T-2 remnants in the downstream half of the study area. After a period of incision, which lowered the stream by approximately 20 m, aggradation occurred. During this period bison bones were deposited in lag gravels, point bar deposits and overbank fines.

A date of 1890 ± 70 yrs B.P.(AECV #1742C) was derived from the left tibia of a bison collected from section 3 in a T-2 remnant. This terrace is 10.2 m above the present channel and the tibia was found 0.9 m below the terrace surface in overbank fines. Upstream, at section 4, the distal two-thirds of a right humerus of a well-muscled bison (probably male, personal comment Dr. Jim Burns, 1993) was dated at 2330 ± 80 yrs B.P.(AECV #1743C). This section rises 11.3 m above the present channel; 9 m of bedrock dominates the exposure with 0.9 m of gravel above the bedrock and 1.1 m of overbank fines and 0.3 m of soil horizon above that. The humerus was found 1.65 m below the surface, 0.25 m below the surface of a lag gravel lens.

The right fibula and right calcaneum of a bison were collected from Section 9 at 0.84 m below the terrace tread. However, these samples had insufficient collagen to date properly and another sample was collected February 6, 1993. At 1.35 m below the terrace surface a right humerus of a bison was found and a blended date of 2150 ± 80 yrs B.P.(AECV #1745C) was determined. Both samples were found in overbank fines above a layer of fine alluvial gravels. The section rose 10.7 m above the present channel with alluvial sediment over 3.85 m thick.

At 15 m above the creek, section 17 is one of the highest T-2 terraces. A date of 2620 ± 70 yrs B.P. (AECV #1749C) was determined on the left ileum of a bison buried 0.9 m below the terrace tread in fine alluvial gravels and covered by point bar fines. A thin layer of lag gravels overlay the bedrock at 1.5 m below the tread.

At 12.7 m above the present channel, section 20 yielded a left mandible of a bison with M1, P2, P3 still intact. This mandible was dated at 2780 ± 80 yrs B.P.(AECV #1751C). Alluvial material was found on bedrock 9 m above the present channel with 2 m of lag gravels, 0.5 m of point bar fines, a fine layer of alluvial gravels and overbank fines. The mandible was found 1.6 m below the terrace tread in a layer of fine alluvial gravel below the separation of the point bar and overbank fines.

The final specimen in the T-2 suite is a left calcaneum (rear hoof) of a bison found in section 40. Dated at 2940 ± 80 yrs B.P.(AECV #1754C) the calcaneum was found in lag gravels 3.74 m below the terrace surface standing 12 m above the channel. With six dates ranging from 2940 to 1890 yrs B.P. the timing of aggradation of T-2 is well defined over a 1000 yr. period.

4.4.5 Phase 3 (T-3)

After a brief period of incision alluvial aggradation resumed forming the terraces found in the T-3 suite. Seven dates document aggradation over the period 1650 to 440 yrs BP.

A date of 1650 ± 70 yrs B.P.(AECV #1741C) was determined from the upper right mandible of a bison containing; P2, P3, P4, M1 and M2 in Section 2. This terrace tread is 5.2 m above the current channel and the mandible was buried 0.57 m below the tread in alluvial gravels of a fining-upward sequence.

Section 5 is 7.2 m above the present channel. It contained a bison bone so badly damaged to be undentifiable. The bone, which was dated at 1350 ± 70 yrs B.P.(AECV #1744C). was discovered among lag gravels ranging in size from boulders to clasts 4 cm in diameter, buried under a fine layer of reworked coal and 0.65 m of point bar and overbank fines. The total depth of the alluvium was ~1 m below the terrace surface.

The left scapula of a young bison, with the articulation of the humer chewed off, was found in Section 11 (Figure 4.13.a) and dated at 1240 ± 80 yrs B.P.(AECV #1746C). The terrace remnant is 7 m above the present channel and 3 m of the section is in alluvium. The scapula was found at 0.43 m below the surface in an organic-rich layer 0.2 m thick. This layer was most likely deposited in an oxbow that was subsequently filled by overbank fines since the oxbow is not visible from either the surface or air.

A date of 1610 ± 70 yrs B.P.(AECV #1748C) was determined from the left and pre maxilla of an older bison which contained; M1, M2 and M3. This maxilla was found 0.7 m below the tread surface of section 15. Boulders 0.5 m in diameter sitting on the bedrock from the base of the alluvium in this exposure. Above these lag gravels are the point bar deposits that contained the maxilla. The slope of the terrace tread clearly documents this terrace was being developed during a time of lateral channel movement.

Section 34 is 7 m above the present channel and contained a bison's left femur that had been chewed. Dated at 720 ± 70 yrs B.P.(AECV #1753C) the femur was 0.8 m below the surface of the terrace tread in a metre of overbank fines. These overbank fines succeed a metre of large boulders and cobbles.

A date of 440 ± 70 yrs B.P.(AECV #1756C) was obtained in section 49 from the left humerus of a bison. This terrace remnant is 5.8 m above the present channel and the humerus was located 0.75 m below the tread. beneath a 0.2 m layer of a fining-upward sequence of fine gravels. to coarse sand. to silts and clays.

Section 52. in a 6.7 m terrace remnant. contained the left horn core of a young male or female bison. It was dated at 750 ± 70 yrs B.P. (AECV #1757C). Located at 0.9 m below the surface tread in point bar fines the horn core had two well buried paleosols above it.

Three dates from sections 34. 49 and 52 are from terraces with thick layers of alluvium. The left femur of a bison that had been chewed and dated at 720 ± 70 yrs B.P. The evidence of chewing raises the possibility that the femur may have been buried by an animal. However. a left humerus of a bison found upstream dated at 440 ± 70 yrs B.P. The humerus lay 0.75 m below the surface. As well. a dated horn core 750 ± 70 yrs B.P. at a depth of 0.9 m support the validity of the initial date. The large amount of overbank fines over the last two finds indicates that aggradation occurred as late as 440 ± 70 yrs BP, before the next stage of incision.

4.4.6 Phase 4 (T-4)

Rapid incision and subsequent aggradation by the Threehills Creek created downstream a defined T-4 suite. The first date for this suite comes from section 14 in a terrace remnant 2.7 m above the current channel. It contained the articulated leg of a young bison. The right femur was removed and used for radiocarbon dating. It was buried in overbank fines 0.4 m below the terrace tread surface and dated at 250 $\pm$ 80 yrs B.P.(AECV 1750C). The bison leg rested on 0.45 m of sandy and silty point bar fines which overlie lag gravels.

In section 19. the left maxilla with P2 and P3 of a young adult bison yielded a date of 150 $\pm$ 80(AECV 1750C). It was located 0.28 m beneath the surface in overbank fines. The terrace tread is 2.95 m above the current channel.

In section 23 the distal end of the right tibia of a bison was dated at 170 $\pm$ 70 yrs B.P.(AECV 1752C). The tibia was buried only 0.12 m below the surface. However. a thin buried paleosol was visible above the specimen. indicating that overbank deposition or even perhaps aeolian deposits during the 1930's may have buried this developing paleosol.

A date of 140 $\pm$ 70 yrs B.P.(AECV 1755C) was determined from the distal three quarters of a bison left tibia found in section 41. 0.3 m beneath the terrace tread in overbank fines. The terrace is 1.3 m above the present creek.

Section 71 contained a the right metacarpal of a bison with a random pattern indenting the bone. This was most likely caused by percussion with rocks in fluvial transport prior to deposition (personal comment. Dr. James Burns. 1993). Dated at 280 $\pm$70 yrs B.P.(AECV 1758C) the metacarpal was found above a buried paleosol at 0.6 m below the terrace tread. There is another paleosol above this at a depth of 0.35 m and a modern soil A horizon. The terrace surface is 2 m above the current channel.

Dates that are younger than 300 yrs B.P. are, "due to radiocarbon activities sufficiently ambiguous only an age of <300 yrs B.P. can be assigned", (Taylor 1987). The close proximity of these dates to the present and the incision that is happening now may be related to human activity over the last 90 years in Alberta.

4.5 Conclusions

The present work investigated the morphological development of Threehills Creek during the Holocene. The alluvial chronological sequence has been developed on the basis of eighteen radiocarbon dates and the presence of Mazama ash. Some relative morphological stages of prairie creek valley development had been previously defined by Rains (1969), Shelford (1975), Welch (1983), Rains and Welch (1988) and Rains et al (1994). The eighteen available dates from Threehills Creek terraces fall into four distinct chronological groups, verifying a consistent, general chronology of the development stages indicated by the alluvial terraces.

In summary, the evidence presented on the morphology, distribution, stratigraphy and chronology of remnant alluvial terraces in the Threehills Creek valley (with correlative evidence on the chronology of the Strawberry, Weed, Whitemud and Ghostpine creeks) shows that:

1) A suite of four terraces exists in the Threehills Creek valley

2) The terrace remnants are commonly paired.

3) The creek displays a composite, concave-convex long profile.

4) The stratigraphies of the alluvium are related to persistent depositional sequences of a meandering channel.

5) Lateral accretion was the dominant mode of floodplain sedimentation throughout Holocene time, but vertical accretion of overbank fines was also significant.

6) The general alluvial chronology now established is:

a) Phase I (T-1) was from some time prior to 8800 yrs. B.P. until as late as 6000 yrs B.P. This terrace would also be partly contemporaneous with the lowest terrace on the Red Deer River, cited by Waters and Rutter (1984), and further supports the work of Rains and Welch (1988) on the North Sasktachewan River, Edmonton.

b) Phase II (T-2) was from some time prior to 3000 yrs B.P. to as late as 1900 yrs BP.

c) Phase III (T-3) was from some time prior to 1600 yrs B.P. to as late as 400 yrs BP.

d) Phase IV (T-4) was from as late as 300 yrs B.P. and includes modern lateral and vertical accretion sediments.

CHAPTER 5. INTERPRETATIONS AND CONCLUSIONS

5.1 Introduction

Preceding chapters outline the geology, surficial geology and glacial history that helped to define the Threehills Creek basin. The third chapter defines the drainage and sets up the types of controls along with common river and creek responses to these controls in Alberta.

The fourth chapter focusses on Threehills Creek basin, in the form of the planimetric terrace distribution, creek longitudinal profile, stratigraphic description of the terraces and chronological development over the Holocene. The present chapter considers the chronological evidence in context of previous studies of creeks and climate change in the Holocene. This defines the geomorphic responses of Threehills Creek basin.

5.2 Holocene Paleoenvironmental Factors

The period from the last continental glaciation to the present day is referred to as the Holocene. In western Canada, the landscape was reshaped by ice erosion and deposition and large-scale ice melting caused extensive fluvial action. The start of the Holocene saw a change in scale from massive geomorphic transformations to slower and more subtle landscape evolution (Sauchyn 1994).

During the Holocene, climate change created successions of vegetation cover. The successive changes in the environment resulted in different types of deposition in different locales that can be recorded. For this reason Mazama ash serves as a significant chronological marker throughout north western North America (Figure 1.3) and is extremely useful in the correlation of other methods of chronological measurement.

Research into the deposition of different types of sediment has shown the Holocene climate to be somewhat cyclical in nature (Figure 5.1). Even though a fine-tuned interpretation of the Holocene's cyclical nature is somewhat in question, overall agreement as to the presence of the Hypsithermal is assured. Originally referred to as the Altithermal, but is now known as the Hypsithermal this was a drier warmer period with climate reaching warmer temperatures than any immediately prior or since today, between 9000-7000 yrs B.P. A paucity of evidence (and also the type and location of evidence that has been gathered) for the early part of the Holocene creates a localized interpretation of the period.

Three very good studies have been done on climate change during the Holocene in Alberta; Lichti-Federovich (1970), Harris and Pip (1973) and Waters (1979). Welch (1983) in his thesis outlined the style of their research, the regions in which they gathered their data, and the assumptions that were made from their data.

To briefly summarize, the study by Lichti-Federovich (1970) (Figure 5.1) was based in central Alberta, 150 km north-northeast of Edmonton at Lofty Lake. She investigated vegetative succession through pollen identification and radiocarbon dates from sediment cores. Inferred climate changes were interpreted from five distinct changes in vegetation. They are as follows: L1) Cooler and moister climate than at present. L2) start of a warming trend with decreased precipitation which continued through L3 and L4 with the warmest and driest period between 5500 and 6000 yrs B.P. From then on came a gradual cooling and wetter climate. L5) The last 3500 years are considered to have been similar to the present climate.

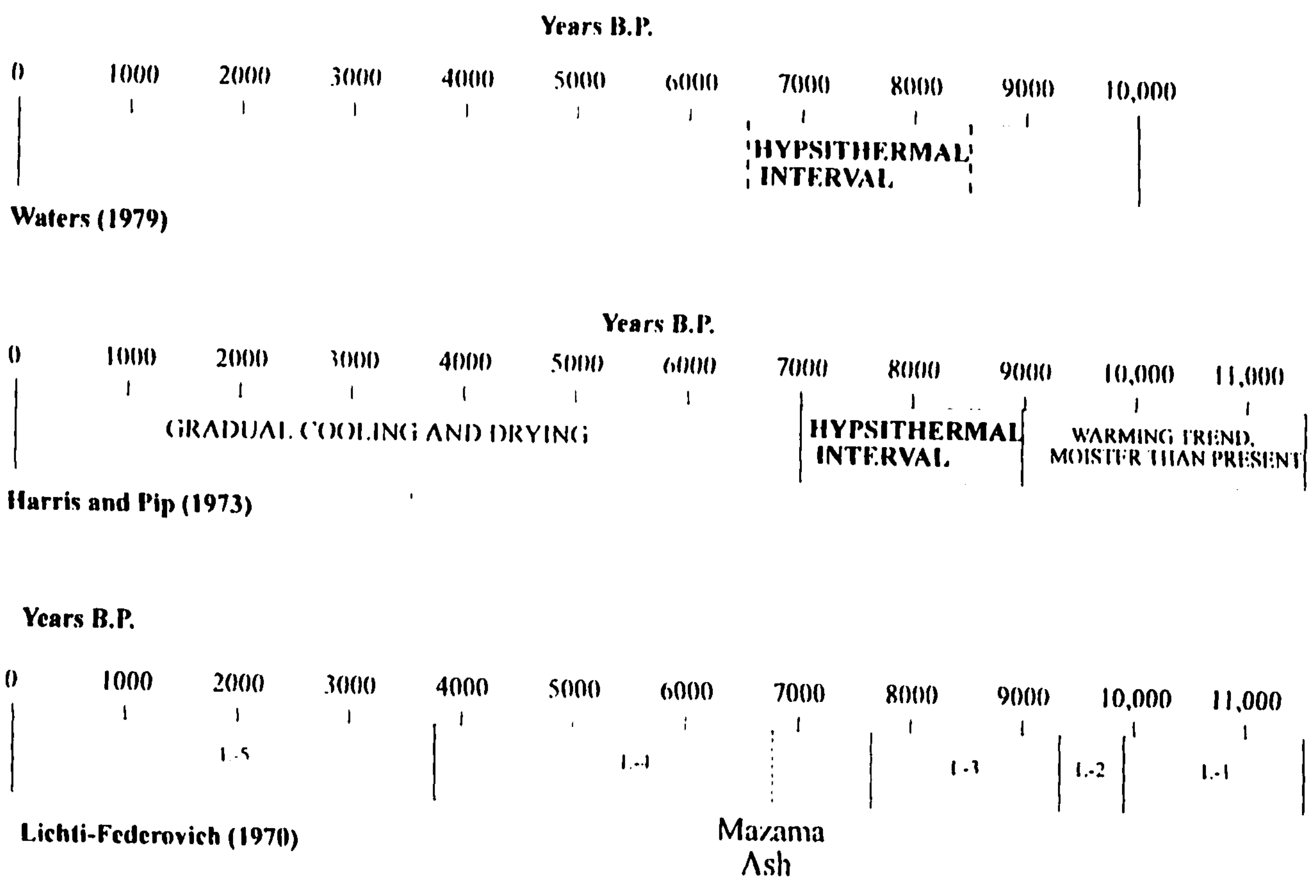


Figure 5.1 Paleo-environmental studies of Waters (1979), Harris and Pip (1973) and Lichti Federovich (1970)

Source Welch (1983)

Harris and Pip (1973) (Figure 5.1) studied molluscan fauna in southwest Alberta. They collected samples, made taxonomic identifications, and used species habitat to create a chronology of postglacial habitat change. They concluded that the initial postglacial climate was similar to today in temperature but was moister than the present. A drier warming trend followed this period with climate reaching warmer temperatures than any immediately prior or since, between 9000-7000 yrs B.P. Harris and Pip (1973) interpreted the climate to have then gradually cooled and that it was drier following the deposition of Mazama ash.

Different types of vegetation have a direct effect upon the soil A horizon developed. Grasslands create paleosols of the Chernozemic order (Waters 1979). From paleosols found in a stratigraphic sequence the identification of the phytolith suite is used to indicate the presence of either short or long grassland vegetation when the paleosol was developed (Waters 1979). From the type of grassland shift that formed the paloesols, the type of climate is inferred (Waters 1979). The occurrence of Mazama ash just above the majority of the paleosols studied by Waters (1979) was useful as a chronological marker.

Rapid vegetative succession from tundra to forests occurred in western Alberta during the transition from glacial to postglacial conditions (Hickman and Schweger 1993). The paleoenvironment that developed the vegetation on the prairies saw the return of seasonal variances of temperature and precipitation, along with cyclical changes over the millennia. This created opportunities for forests, bogs, lakes, short and long grass prairies and combinations where varying soils, slopes and aspects of the slopes created micro environments (Klassen 1993, Sauchyn 1994).

The time-line (Figure 5.1) that Waters (1979) created starts at 10,000 yrs B.P. reflecting the data which were collected from grassland paleosols. She suggested that immediately following deglaciation the climate was warmer and wetter than present, quickly followed by the Hypsithermal which was warmer and drier, starting around 8500 and ending at 6600 yrs B.P., at the time of Mazama ash deposition. Immediately following the Hypsithermal there developed a cooler and wetter environment than is present today (Figure 5.1).

East of the Foothills precipitation progressively decreases in quantity as summer temperatures increase (Williams and Masterton 1983, Hickman and Schweger 1993). The most visible changes eastward are the transitions from montane boreal forest to aspen parkland to prairie grassland. Less visible, but measurable, is the increase in lake salinity east of the Foothills (Northcotte and Larkin 1963, Hickman and Schweger 1993).

Welch (1983) chose to follow the time-line presented by Waters (1979). I will also base my interpretations using her time-line to define the Hypsithermal. My reasons areas follows: Threehills Creek Basin which is east of the Foothills is an area dominated by prairie grassland; and the stratigraphic sections that she studied were fluvial; specifically her work at the Joffre site on the Red Deer River.

5.3 Origin of the Terraces

Within this overall climate cycle, there are smaller discrete cycles. Depending upon the region studied, different techniques have been developed to create a climatic record for that region. These techniques have varying sensitivity to climate. So a correlation with surrounding regional data obtained using different methodology must be used along with data from the development of the Threehills Creek terraces to create the most plausible paleoclimatic scenario for Threehills Creek basin.

The area around the Cypress Hills was deglaciated by ~13,500 yrs B.P. (Klassen 1993). Findings of datable wood, peat and seeds present an image of aspen forest, along with bogs, covering the area from 13,500 to 13,000 yrs B.P. (Sauchyn and Sauchyn 1991, Klassen 1993, Sauchyn 1994) This was replaced with a mix of forest and grassland ~9500 yrs B.P. By 9,000 yrs B.P. the area around the Cypress Hills was replaced by a pure grasslands regime. In southwestern Alberta, Waters (1979) noted this transition period to be around 10,000 to 9500 yrs B.P.

Ghostpine, Mudspring, Michichi and Threehills pond are all assumed to have been part of the larger system Glacial Lake Drumheller. Based upon radiocarbon dating of gastropods, Michichi pond drained as late as 10,010 ± 70 yrs B.P.(TO-1830) (Young et al. 1993). This would Indicate headward extension of Michichi Creek from the Red Deer River valley to have taken 2,000-3000 years to encroach on the pond basin. With the assumption that similiar controls affected all the ponds, Threehills pond is assumed to have drained at about the same period as Michichi.

The linear shape of Threehills basin, with its bedrock controlled relief, funnels drainage through gullies and infiltration into Threehills Creek. Initially the creek meandered over a wide area of nearly level lacustrine deposits, quickly incising through this material into the underlying till and then bedrock. Evidence of strath terraces occurs as far back in the valley system as J-J' (Figure 4.10.j), where rapid incision created valley walls which limited the lateral movement of creek and focussed the stream energy within the valley. Steep valley walls predominate in the downstream section of the creek. Further upstream the meandering of the creek created a wider valley with gentler-sloped valley walls cross-section profiles (Figure 4.10.a - 4.10.j). It is at these wider sections of the valley that alluvial sediment accumulated in floodplains, to be later partially removed by the lateral action of the creek. The sediment load of the stream would have also been high at the time of initial incision due to the abundance of lacustrine sediment.

From 10,000 yrs B.P. till ~8500 yrs B.P. the climate was probably warmer and moister than at present. The Threehills Creek responded by incising. A combination of factors may then have caused the transformation from a degrading to an aggrading channel. The advent of the warmer, drier Hypsithermal at around 8500 yrs B.P. would have decreased the stream energy by reducing precipitation and increasing potential evapotranspiration. With the heavy sediment load from the lacustrine deposits in the floodplains, and the reduced energy in the system, it would be safe to say that the system reached a point of stability and aggradation dominated.

The Hypsithermal period was more arid than the time immediately following deglaciation, and depending upon the location of the study area the estimates for precipitation vary. Barnosky (1989) determined that this period in northwest Montana lasted from about 9300 to 6000 yrs B.P. Pennock (1984) estimated its duration from 7900 to 5180 yrs B.P. using data from the Highwood River basin in southwestern Alberta. MacDonald (1989) studied subalpine forest and grasslands in southwest Alberta and determined this region to have been affected by the Hypsithermal from 7700 to 5500 yrs B.P. From Harris Lake in southwestern Saskatchewan, Sauchyn and Sauchyn (1991) present the extent of this phase as 7700 to 5000 yrs B.P.

Without the support of older radiocarbon dates, from within the alluvial sequences of any of the T-1 remnants in Threehills Creek basin, a more accurate definition of that period of aggradation is left to speculation. With the positive identification of Mazama ash within the terrace represented by sections 94 and 95 of Threehills Creek, the terrace deposition is known to have begun prior to that tephra deposition and the Mazama ash layer was quickly covered with alluvial sediment. How long the terrace remnant was an active part of the floodplain is not clear but it could be safely assumed from the longitudinal profile that the system had finished aggrading sometime after the tephra deposition and in the system would cause subsequent incision.

In Dinosaur Provincial Park, Red Deer River valley, badland development decreased with an increase in infiltration and a decrease in runoff from about 6000 to 5000 yrs B.P. (O'Hara and Campbell 1993). The period from 4500 to 3000 yrs B.P. is interpreted as being cooler and moister as an expansion of forest in the Cypress Hills area indicates increased effective moisture (Sauchyn 1994). A reduction in salinity was noted at Chappice Lake, northeast of Medicine Hat, Alberta, due to an increase of moisture from about 4400 to 2600 yrs B.P. (Vance et al. 1992).

With these three known factors, a drier period that decreased erosion, followed by one of the wettest times in the Holocene since deglaciation, it is reasonable to deduce that Threehills Creek incised into the valley, from about 4500 yrs B.P. to 3000 yrs B.P.

In the Canadian Rocky Mountains a "mid neo-glacial" glacial advance occurred (Denton and Karlen 1977, Ryder and Thomson 1986, Luckman et al. 1990, Sauchyn 1994), coinciding with a cooled environment globally during 3000 to 2400 yrs B.P. From 2600 to 1000 yrs B.P., Chappice Lake maintained a high level and low salinity (Vance et al. 1992.

The oldest recorded radiocarbon dates from the T-2 remnants are 2940, 2780, 2620, and 2330 yrs B.P. They were all found in either lag gravels or point bar deposits, indicating that they were deposited during lateral deposition while this 12 m terrace was in its early stage of formation. We know that active aggradation of T-2 had started by 3000 yrs B.P. The youngest two dates in the suite are 2150 and 1890 yrs B.P. Both were found in a metre of overbank fines in a 10 m terrace remnant. Therefore, we know the T-2 system was aggrading laterally and/or vertically from circa 3000 to 1900 yrs B.P.

Although there is no recorded change in climate for the period of 2000 to 1600 yrs B.P. there appears to have been an increase in fluvial activity at Lower Falcon valley (a Red Deer River tributary) which created terrace-like surfaces on the alluvial fans (O'Hara and Campbell 1993). Little Sandhill Creek, a small tributary of the Red Deer River in Dinosaur Provincial Park, also commenced incising from 2000 yrs B.P. (Campbell and Evans 1990). Barling (1995, p. iv) states, "Material obtained from terrace alluvium in Matzhiwin Creek (and from other creeks in central and southern Alberta) which has been radiocarbon dated indicates major episodes of stream aggradation and incision post 4000 yrs B.P.," and gives estimated time-frames for those episodes.

The geomorphic balance of Threehills Creek basin was poised for the next period of incision. Although this period was brief, significant incision of 4 to 5 m occurred, creating a new suite of paired terraces (T-3). The oldest set of T-3 paired terraces dated at about 1650, 1610 and 1350 yrs B.P. Specimens collected from these terrace remnants, are partly from lateral accretion deposits. The four younger dates, 1240, 750, 720 and 440 yrs B.P. of the T-3 sequence are from vertically accreted overbank fines, which would indicate that the creek's major form of aggradation at this point was through vertical accretion of the floodplain.

At Chappice Lake (Vance et al. 1992), the period of 1000 to 600 yrs B.P., the Medieval Warm period (Bryson et al. 1970, Gribbin and Lamb 1978), showed significant cycles of drought. Near the same period, 800 to 600 yrs B.P., Lower Falcon valley was aggrading (O'Hara and Campbell 1993).

Cooler temperatures and more effective moisture during the Little Ice Age (Gribbin and Lamb 1978, Luckman 1986), the period of 600 to 100 yrs B.P., affected the prairies, as well. From 600 to 200 yrs B.P. incision was occurring at Lower Falcon valley (O'Hara and Campbell 1993) and a return to higher water level at Chappice Lake occurred from 600 to 100 yrs B.P. (Vance et al. 1992)

The Little Ice Age brought cooler and moister temperatures and incision started soon after 400 yrs B.P., most notably along the downstream section of Threehills Creek, lowering the profile by 4 to 5 m. However, dates from alluvium in the T-4 suite, range in age from only 250 to 140 yrs B.P. Difficulty with exact dates is due to radiocarbon dating being unreliable for dates younger than 300 yrs B.P., making necessary the conclusion that all these dates are simply younger than 300 yrs B.P. Most T-4 datable materials found were in overbank deposits. However, the low height of the modern floodplain above the creek made it difficult to find material to date closer to the zone of lateral accretion.

5.4 Conclusion

In conclusion, there are definite trends in deposition and incision with clusters of dates from the terrace suites providing a chronology. A period of stream incision occurs during a wetter and/or cooler period. As the climate becomes drier or warmer the stream initially aggrades by lateral and vertical accretion. The floodplain accretes predominately by overbank deposition, with stream migration causing lateral accretion as well as eroding the floodplain as it meanders laterally. The next step is for a geomorphic threshold to be reached. In the case of the first terrace sequence it took ~5500 yrs to be completed; then ~2700 years until the next cycle was completed and ~1200 years for the third cycle to run. The 4th cycle is still in progress.

Threehills Creek basin responded to climatic variations with a definite signature of degradation and aggradation that correlates with the findings of other research done in similar regions. It is shown here that, as Schumm (1993) had noted, a semi-arid environment can record sensitive inputs to stream terraces. Threehills Creek reached a geomorphic threshold where terraces could only aggrade through vertical deposition during episodic floods. How long each of the floodplains accreted depended upon the next geomorphic threshold. In Threehills Creek basin during the Holocene it seems that the thresholds have been dominated by climate changes.

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Appendix A

Radiocarbon date: 2940 ± 80 yrs B.P.

Lab number: AECV-1754C

Terrace: T-2

Section location: Figure 4.4, 4.5

Alluvial stratigraphic section: Section 40, Figure 4.16

Radiocarbon dated material: Bone; bison left calcaneum

Stratigraphic Position: Bone was extracted from lag gravels 3.74 m below the terrace tread surface.

Radiocarbon date: 2780 ± 80 yrs B.P.

Lab number: AECV-1751

Terrace: T-2

Section location: Figure 4.4

Alluvial stratigraphic section: Section 20, Figure 4.15

Radiocarbon dated material: Bone; bison left mandible with M1, P2, and P3 intact.

Stratigraphic Position: the bone was extracted from point bar fines 1.6 m below the terrace tread surface.

Radiocarbon date: 2620 ± 70 yrs B.P.

Lab number: AECV-1749C

Terrace: T-2

Section location: Figure 4.4, 4.5

Alluvial stratigraphic section: Section 17, Figure 4.15

Radiocarbon dated material: Bone; bison left ilium

Stratigraphic Position: Bone was extracted 0.9 m below the terrace tread in fine alluvial gravels and point bar fines.

Radiocarbon date: 2330 $\pm$ 80 yrs B.P.

Lab number: AECV-1743C

Terrace: T-2

Section location: Figure 4.3

Alluvial stratigraphic section: Section 4, Figure 4.15

Radiocarbon dated material: Bone: bison (well muscled adult probably male) distal two-thirds of a right humerus.

Stratigraphic Position: found 0.25 m deep in a 0.9 m lag gravel lens, with 1.1 m of overbank fines and 0.3 m of soil horizon above that. In total 1.65 m below the terrace tread surface.

Radiocarbon date: 2150 $\pm$ 80 yrs B.P.

Lab number: AECV-1745C

Terrace: T-2

Section location: Figure 4.3

Alluvial stratigraphic section: Section 9, Figure 4.15

Radiocarbon dated material: Bone; Blended date, same terrace section, bison's right fibula and right calcaneum and bison 's right humerus.

Stratigraphic Position: right fibula and right calcaneum were found 0.84 m below terrace surface in overbank fines. Right humerus was found in the same overbank fines 1.35 m below the terrace tread 5 m upstream from the first collected sample. Radiocarbon date: 1350 + 70 yrs B.P.

Radiocarbon date: 1890 ± 70 yrs B.P.

Lab number: AECV-1742C

Terrace: T-2

Section location: Figure 4.3

Alluvial stratigraphic section: Section 3, Figure 4.15

Radiocarbon dated material: Bone; bison, left tibia

Stratigraphic Position: 0.9 m below terrace surface in overbank fines.

Radiocarbon date: 1650 ± 70 yrs B.P.

Lab number: AECV-1741C

Terrace: T-3

Section location: Figure 4.3

Alluvial stratigraphic section: Section 2, Figure 4.17

Radiocarbon dated material: Bone; bison upper right mandible containing P2, P3, P4, M1 and M2

Stratigraphic Position: buried 0.57 m below the terrace surface in alluvial gravels.

Radiocarbon date: 1610 ± 70 yrs B.P.

Lab number: AECV-1748C

Terrace: T-3

Section location: Figure 4.4

Alluvial stratigraphic section: Section 15, Figure 4.17

Radiocarbon dated material: Bone; older bison's left and pre maxilla which contained M1, M2 and M3.

Stratigraphic Position: The pre maxilla was extracted from point bar deposits 0.7 m below the terrace tread surface.

Radiocarbon date: 1350 ± 70 yrs B.P.

Lab number: AECV-1744C

Terrace: T-3

Section location: Figure 4.3

Alluvial stratigraphic section: Section 5, Figure 4.17

Radiocarbon dated material: Bone ; bison, undefinable.

Stratigraphic Position: extracted from lag gravels below 65 cm of point bar and overbank fines.

Radiocarbon date: 1240 ± 80 yrs B.P.

Lab number: AECV-1746C

Terrace: T-3

Section location: Figure 4.3

Alluvial stratigraphic section: Section 11, Figure 4.17

Radiocarbon dated material: Bone, bison (young) left scapula with the articulation of the left humer chewed off.

Stratigraphic Position: The scapula was found in overbank fines 0.43 m below the terrace surface.

Radiocarbon date: 750 ± 70 yrs B.P.

Lab number: AECV-1757C

Terrace: T-3

Section location: Figure 4.5

Alluvial stratigraphic section: Section 52, Figure 4.19

Radiocarbon dated material: Bone; bison (young male or female) left horn core.

Stratigraphic Position: extracted from 0.9 m below the surface tread in point bar fines.

Radiocarbon date: 720 $\pm$ 70 yrs. B.P.

Lab number: AECV-1753C

Terrace: T-3

Section location: Figure 4.4

Alluvial stratigraphic section: Section 34, Figure 4.18

Radiocarbon dated material: Bone; bison left femur, chewed.

Stratigraphic Position: 0.8 m below the terrace tread surface in overbank fines.

Radiocarbon date: 440 $\pm$ 70 yrs B.P.

Lab number: AECV-1756C

Terrace: T-3

Section location: Figure 4.5

Alluvial stratigraphic section: Section 49, Figure 4.18

Radiocarbon dated material: Bone; bison left humerus.

Stratigraphic Position: Humerus was extracted 0.75 m below the terrace tread surface from a fining upward sequence of fine gravels, coarse sand to silts and clays.

Radiocarbon date: 280 $\pm$ 70 yrs B.P.

Lab number: AECV-1758C

Terrace: T-4

Section location: Figure 4.5, 4.6

Alluvial stratigraphic section: Section 71, Figure 4.18

Radiocarbon dated material: Bone; bison left metacarpal, random pattern from percussion with rocks during deposition.

Stratigraphic Position: extracted 0.6 m below the terrace tread surface in overbank fines.

Radiocarbon date: 250 ± 80 yrs B.P.

Lab number: AECV-1747C

Terrace: T-4

Section location: Figure 4.4

Alluvial stratigraphic section: Section 14, Figure 4.20

Radiocarbon dated material: Bone; young bison, right femur was removed from the articulated leg for radiocarbon dating.

Stratigraphic Position: Femur was extracted from overbank fines 0.4 m below terrace tread surface.

Radiocarbon date: 170 ± 70 yrs B.P.

Lab number: AECV-1752

Terrace: T-4

Section location: Figure 4.4

Alluvial stratigraphic section: Section 23, Figure 4.20

Radiocarbon dated material: Bone; bison right tibia

Stratigraphic Position: The tibia was removed 0.12 m below the terrace tread surface from overbank deposits.

Radiocarbon date: 150 ± 80 yrs B.P.

Lab number: AECV-1750C

Terrace: T-4

Section location: Figure 4.4

Alluvial stratigraphic section: Section 19, Figure 4.20

Radiocarbon dated material: Bone; bison (young adult), left maxilla with P2 and P3 intact.

Stratigraphic Position: extracted from overbank fines 0.28 m below the terrace tread surface.

Radiocarbon date: 140 ± 70 yrs B.P.

Lab number: AECV-1755C

Terrace: T-4

Section location: Figure 4.4, 4.5

Alluvial stratigraphic section: Section 41, Figure 4.20

Radiocarbon dated material: Bone: distal three-quarters of a bison's left tibia.

Stratigraphic Position: Extracted from overbank fines 0.3 m beneath the terrace tread surface.