CENOZOIC DRAINAGE HISTORY OF
SOUTHERN BRITISH COLUMBIA

By

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ABSTRACT

Anomalous geomorphology, valley-fill geology and cross-cutting relationships throughout the southern Interior Plateau of British Columbia indicate the area retains relict or exhumed landforms of Late Cretaceous and Cenozoic age. Preglacial valleys and other landforms are identified on high-resolution shaded relief maps, and their ages are bracketed by geological and structural relationships. Drainage anomalies, such as valley-floor divides, underfit streams and graded valley segments, indicate former base levels in the landscape. Reconstructions of past landscapes and waterways are presented for six time intervals spanning the last 100 million years.

Regional base level was relatively stable at 1000-1300 m elevation during the Mesozoic. From Late Cretaceous to the middle Eocene, base level fell 500-700 m, resulting in incision of valleys. Some valleys filled with sediments to an elevation of about 900 m from middle Eocene to Miocene time. Following the Miocene, base level dropped significantly, eroding canyons and exhuming older, partially buried valleys. Changes in base level over the last 100 Ma are greatest in the southern Interior Plateau and are least in the Quesnel-Horsefly area.

Regional drainage was broadly northward throughout the Cenozoic. An anabranching river system flowed northwestward across Cariboo Plateau to Fraser River valley from Quesnel and Shuswap Highlands during Late Cretaceous to Cenozoic time. Other valleys dating back to middle Eocene time and possibly earlier are those of North Thompson River south of Clearwater, Thompson River from Kamloops to Spences Bridge, Nicola Lake, Hat Creek, Bridge River, Seton River, and Okanagan Valley north of Penticton. Miocene rivers in the Coast Mountains flowed northeastward across Thompson Plateau and northward along Clearwater and Quesnel river valleys. Modern southward drainage along Okanagan, Kettle, Thompson and Fraser rivers was established after Miocene time.
That old river keeps on flowing, though,
No matter what gets in the way
Or which way the wind does blow

— Bob Dylan
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INTRODUCTION

Studies of landscape and drainage evolution were popular during the 19th century and the first half of the 20th century as geologists examined the geomorphic implications of uniformitarianism (Bloom, 1978; Summerfield, 2000). In western Canada, geologists applied new concepts of landscape evolution, such as base level, peneplain and cycle of erosion, to infer that parts of the landscape developed during early Cenozoic time (Dawson, 1895; Drysdale, 1914; Uglow, 1923). Observations of stream patterns in British Columbia led to the idea that south-flowing Fraser River once flowed to the north sometime in the Cenozoic (Dawson, 1895; Lay, 1940).

Regional-scale studies of landscape development waned during the last half of the 20th century as the focus of geomorphological research changed to macro- and micro-scale studies of processes and rates. Advances in age dating and instrumentation technology accelerated research in these fields. One outcome of this shift in focus that is germane to the development of British Columbia's landscape and to this thesis, was more research on mechanisms and rates of glacial erosion and deposition. The focus on small spatial and short temporal scales, and an appreciation of the erosive power of glaciers, led to the conclusion that the landscape is glacial in origin and developed over the past 3 Ma or so.

Such a conclusion is undeniable at the macro-scale. Glacial deposits and landforms are ubiquitous throughout Canada. Almost 3 million years of repeated glaciations in British Columbia have left a complex stratigraphic record and many glacial erosional forms. Yet, how does one reconcile evidence of the glacial origin of landforms with century-old observations that the landscape predates glaciations by many millions of years? The key is scale.

The development of computer technology and digital geographic data sets during the past few decades has led to a revival of regional-scale geomorphological research. Digital techniques allow large georeferenced data sets to be handled with ease. High-resolution digital elevation models provide an accurate and detailed rendering of the ground surface over large areas. Prior to these developments, the land surface was
depicted in topographic maps and hand-drawn relief maps, which had limited accuracy and lacked detail.

This thesis research was conceived in order to (1) depict British Columbia's landscape in detail, and (2) determine how far back in time drainage patterns and landforms can be traced. It uses new data and computer techniques to revisit an old problem, the history of the landscape.

A new shaded relief map of the province was produced to depict British Columbia's landscape with photograph-like resolution. The map provides the most detailed rendering of the landscape available to date and is derived from a digital elevation model with 25 m spacing of data points. The data and methodology used to create the shaded relief map are explained in Chapter One.

The rest of the thesis is concerned with the problem of landscape and drainage evolution, and the age of landforms. Map interpretation and geologic synthesis were used to reconstruct Cenozoic landscapes and drainage networks in southern British Columbia. Landform age was bracketed by cross-cutting relationships with dated bedrock geology. Physiography and drainage reconstructions are presented for six intervals during the last 100 Ma. Results presented here suggest that some landforms are relict or exhumed features dating back 50 Ma or more. They persist despite having been modified by glaciation and subaerial erosion. Other landforms are much younger and were formed during or after glaciation.

**Field Work**

Field observations were carried out over one to several weeks during each of four field seasons from 2000 to 2003. During this time, the author travelled throughout the study area up to near 54°N and examined documented Late Cretaceous and Cenozoic sedimentary and volcanic rocks. Examination included measurements of elevation and dips, and observations of lithology, structure and geomorphology. Geomorphology seen throughout the study area was compared to the shaded relief renderings. Terrain elevations were checked against DEM elevations using a 12-channel Global Positioning System.
Thesis Format

Chapter One describes the data and methodology used to create the detailed shaded relief map of British Columbia. The map will be published as a Geological Survey of Canada Open File and CD-ROM. Citations for this work are:


Chapters 2-5 are four papers. Each chapter is organized in manuscript style with an abstract, introduction, discussion, conclusion, figures and tables. The first three papers are either published or submitted to a journal at the time of writing. Minor revisions to the text of the published or submitted papers have been incorporated into the chapters presented here. Citations are as follows:


Chapter 5. Tribe, S., (manuscript), Late Cretaceous and Cenozoic paleodrainage in the southern Interior Plateau, British Columbia

The concluding chapter, Chapter 6, summarizes the main results of the thesis research. A single master reference list is found at the end of the thesis.
Because of the paper format of the thesis, space did not permit the presentation of large-scale geologic maps in the body of the chapters. A more detailed view of physiography and geology can be found in Appendix A, which contains 15 maps showing shaded relief and bedrock geology for key locations in the study area. The maps are presented at a nominal scale of 1:400,000, and are near the resolution limit of the original data set. Geology is taken from digital files listed in the references. The geological time scale used is Okulitch (2002).
Introduction

The shaded relief map of British Columbia provides an accurate and highly detailed, bird's-eye view of the province's landscape at 1:1,500,000-scale with 75 m resolution (Fig. 1; Tribe, in press). Although the map resembles a satellite image or aerial photograph, it is computer-generated from an array of elevation values, or digital elevation model (DEM). The map depicts ground relief in vertical perspective using light and dark areas to represent steep illuminated and overcast slopes, and intermediate gray tones to represent gentle slopes. Relief is vertically exaggerated in this map to enhance surface detail. One millimetre on the map corresponds to 1.4 km on the ground. Some major roads and towns are shown for reference.

Previous Shaded Relief Portrayals

The new shaded relief map of British Columbia was inspired by Thelin and Pike's (1991) shaded relief portrayal of the conterminous United States of America. A previous depiction of British Columbia's relief was made by Kung and Sawyer (1997). However, the new shaded relief map shown in Figure 1 depicts landforms with greater detail and accuracy. Other regional shaded relief maps have been published for Alaska, Sweden, Australia and South Africa (Thelin and Pike, 1991; Riehle et al., 1997).

Source Data

The map was made from 25-m, gridded digital elevation data provided by Base Mapping and Geomatics Services Branch, Ministry of Sustainable Resource Management, British Columbia. The original data consisted of 84 DEM files, one for each of the eighty-four, 1:250,000-scale, NTS map sheets that cover the province.

Gridded DEM files were derived from 1:20,000-scale Terrain Resource Inventory Mapping (TRIM) digital maps that, in turn, were produced from aerial photographs. The accuracy of the gridded DEM is equivalent to that of 1:20,000-scale TRIM data. Ninety percent of all interpolated points are accurate to within 5 m of their true horizontal position and 10 m of their true vertical elevation.
Methodology

Computer map processing was done using Arc/Info 8 software on a personal computer. Each DEM file was reprojected from the original Universal Transverse Mercator (UTM) projection to Lambert Conformal Conic. UTM projections provide good scaling for small areas. Each UTM zone is a separate projection, thus adjacent UTM zones cannot be tiled together without significant distortion along zone boundaries. Lambert Conformal Conic projection was chosen because of its good scaling properties for land masses with a dominant east-west extent (Snyder, 1987). The map datum is NAD83.

The eighty-four reprojected DEM files were then mosaiced into a single seamless file of elevation values that covered the entire province. This file was then resampled to 75 m to reduce the size of the dataset. The final DEM contains 200 million data points, each 75 m apart on the ground, corresponding to a maximum resolution of 0.05 mm per pixel on the map.

A hillshade algorithm was applied to each point in the resampled DEM to form the gray-scale shaded relief image. The hillshade algorithm calculates the reflected light intensity from an artificial light source shining on each point of the digital land surface, and represents the illuminated or overcast areas as gray-scale pixels. The light source is located in the northwest (azimuth 315°) and 30 degrees above the horizon. The light source is lower than usually used for such maps. A lower elevation provides more shadow detail in low-relief areas.

A colour inset map depicts elevations in metres above sea level throughout the province. To make this map, elevation points in the resampled DEM were binned into classes of equal elevation range and assigned a colour. The colour-coding revealed details of the topography not visible in the gray-scale shaded relief map, particularly in the low-relief landscape of the central part of the province. A second inset map depicts the main physiographic subdivisions of British Columbia from Mathews (1986).

Physiography of British Columbia

The physiography of the Canadian Cordillera was first described by Bostock (1948). Holland (1976) provided the first detailed description of the physiography of the entire province, which was later modified by Mathews (1986). Their classifications were
based on interpretation of aerial photographs, topographic maps and field work, and were presented at 1:2 000 000-scale or smaller. The published maps provide a general description of the landscape but do not have the detail and scope possible today with high-resolution DEMs.

The main physiographic divisions of British Columbia are clearly visible on Figure 1. The 200 km-wide Coast Mountains trend northwest along the western margin of the province from Vancouver to 60°N latitude. Farther west and offshore are largely mountainous Vancouver Island and the Queen Charlotte Islands. The low-relief terrain of the Interior Plateau is visible in the central part of the province from south of Kelowna to northwest of Prince George. The plateau is surrounded by the Omenica, Skeena and Cassiar Mountains to the north and the Cariboo, Selkirk and Purcell Mountains to the southeast. These mountain ranges and the central plateau are bounded on the east by the Rocky Mountain Trench, which extends northwest along the length of the province from Cranbrook to the north-central region. High-relief terrain east of the trench forms the Rocky Mountains. The low-relief landscape in northeastern British Columbia is part of the Alberta Plateau.

Acknowledgments

Base Mapping and Geomatics Services Branch, Ministry of Sustainable Resource Management, British Columbia provided the digital data. John Clague, Bob Anderson and Robert Cocking provided significant support and assistance during the making of the map. I also thank Robert Kung and Kurtis Halingten for their assistance with this project.
Figure 1. Digital shaded relief map of British Columbia. The original 48" x 52" wall-map is 1:1 500 000-scale, and published as a Geological Survey of Canada Open File.
CHAPTER TWO
GEOMORPHIC EVIDENCE FOR TERTIARY DRAINAGE NETWORKS IN THE SOUTHERN COAST MOUNTAINS, BRITISH COLUMBIA

Abstract

Cenozoic drainage networks are reconstructed by mapping drainage anomalies and valley trends on shaded relief maps of the southern Coast Mountains (NTS 92G, H, I, J). Geological and structural relationships provide age constraints for the valleys. In the vicinity of Gold Bridge, ancestral Bridge River and Seton River flowed northeast sometime between latest Cretaceous and Eocene time. Strike-slip faulting along the Yalakom and Fraser faults diverted the rivers to the southeast during Eocene time. Lillooet River valley crosscut and captured the headwaters of the ancestral Bridge and Seton rivers. Geomorphic evidence indicates an ancestral Fraser River did not flow south along the trace of the Fraser Fault until sometime after Eocene strike-slip faulting. A dendritic network of streams developed throughout the region in Miocene time, and incised during Miocene-Pliocene regional uplift.

Introduction

Valleys in the Coast Mountains physiographic province (Holland, 1976) of British Columbia have been shaped by river erosion, glaciation, mass wasting and tectonic processes. But for how long have these landforms persisted? Anomalous drainage patterns, such as underfit streams, elongate lakes in rock-walled valleys and crosscutting valley trends, indicate that some valleys in the southern Coast Mountains are relict landforms. Geological and structural relationships suggest that the valleys date back to Eocene time and possibly earlier.

In this study, drainage network evolution is reconstructed by interpreting shaded relief maps made from high-resolution digital elevation models. Such maps depict Earth's topography with greater resolution and accuracy than topographic maps. They allow landforms to be mapped with the detail possible only with stereo aerial photograph interpretation (e.g., 1:50 000 scale) at scales more common to satellite images (1:1 000 000 scale or smaller). Published geological reports and maps, including digital files of lithology and structure, provide constraints on the age of the suspected relict landforms.
This paper describes and assigns ages to relict valleys observed in the southern Coast Mountains.

**Data Sources**

Shaded relief maps used in this study were made from 1:250 000-scale, 25-m gridded digital elevation models available from Geographic Data BC, using Arc/Info and ArcView software on a personal computer. Digital files of streams, bedrock geology and faults were obtained from Journeay and Monger (1998). Numerous maps and reports published by the Geological Survey of Canada and other researchers were examined.

**Geology and Structure of the Study Area**

Bedrock geology in the northeast part of the study area between Gold Bridge and Lillooet consists of fault-bounded, northwest-trending terranes of Paleozoic and Mesozoic age (Journeay and Monger, 1994). Elsewhere, geology is dominated by Jurassic to Late Cretaceous intrusive rocks of the Coast Plutonic Complex with minor northwest-trending septa of older volcanic and sedimentary rocks. Eocene and Miocene intrusions and Miocene volcanic rocks are scattered throughout the study area. Pleistocene and Holocene volcanic rocks are present north of Squamish. Figure 2 shows the distribution of mapped Tertiary and Quaternary rocks. A few small Tertiary outcrops south of Hope and east of Fraser River are omitted for sake of clarity.

Northwest-trending faults are common throughout the study area and fall into two groups. The first group consists of Mesozoic to early Tertiary thrust and strike-slip faults (Fig. 3). The Ashlu, Fire and Owl creek faults are thrust faults thought to have been active in Late Cretaceous time (Monger and Journeay, 1994). Harrison Lake Fault is a dextral strike-slip fault dated at 93.5 ± 11.5 Ma (Monger and Journeay, 1994). Downton Creek Fault System accommodated both southwest-directed thrusting and dextral strike-slip movement (Monger and Journeay, 1994). It is estimated to have been active from 85 to 65 Ma, with most activity between 69 Ma and 67 Ma (Umhoefer and Schiarizza, 1996).

The second group of faults is found in the northeast part of the study area and consists of northwest-striking early Tertiary strike-slip and normal faults (Fig. 3). Yalakom Fault System accumulated 100 to 170 km of right-lateral strike-slip offset from 57 to 45 Ma (Schiarizza et al., 1997). The Fraser Fault accommodated 80 to 120 km of
right-lateral strike-slip displacement between 47 and 35 Ma ago (Monger and Journeay, 1994). The Mission Ridge Fault is a low-angle, northeast-dipping normal fault that was active 45 to 44 Ma ago (Schiarizza et al., 1997). The southwest-dipping Marshall Creek Fault is estimated to have 3.5 km of normal displacement (Coleman and Parrish, 1991) and at least 10 km of dextral strike-slip movement (Monger and Journeay, 1994) sometime between 44 and 34 Ma ago (Garver et al., 1994; Schiarizza et al., 1997).

**Geomorphic Evidence of Relict Valleys**

The shaded relief map (Fig. 3) shows a high-relief mountainous terrain that is heavily dissected by valleys of different sizes and patterns. The prominent southeast-trending valleys that convey modern Fraser and Lillooet rivers are the largest valleys in the region. Lillooet River valley is 200 km long, ranges in width from 2 to 10 km and has relief of up to 2300 m.

Oblique to the southeast-trending valleys, but almost as large, are a set of northeast- and east-trending valleys containing Bridge and Seton rivers. These valleys appear to be contiguous across Lillooet River with the valleys of Meager Creek and Green–Cheakamus rivers, respectively. The broadly sinuous, northeast-trending valleys have lengths of up to 100 km, widths of 2 to 3 km and relief of more than 2100 m. Near the town of Gold Bridge, Bridge River valley and the large tributary valley drained by Hurley River both attain widths of 5 km or more. In the region between Lillooet and Fraser rivers, a set of narrower, but still large, northeast-trending valleys contain Cayoosh Creek, Stein River and Nahatlatch River.

Many of the northeast-trending valleys contain elongate natural lakes bounded by steep rock walls (Fig. 4). Examples include Anderson Lake (290 m asl) and Seton Lake (243 m asl) within Seton River valley, Gun Lake (940 m asl) in Bridge River valley, Duffey Lake (1120 m asl) in Cayoosh Creek valley, and Nahatlatch Lake (300 m asl) along Nahatlatch River. Carpenter and Downton lakes, in Bridge River valley, are man-made lakes. Prior to damming, Bridge River valley contained a meandering underfit stream.

Many of the northeast-trending valleys contain mid-valley drainage divides from which underfit streams flow southwestward into Lillooet River (Fig. 3). Salal Creek and Boulder Creek flow southwesterly from drainage divides in Bridge River valley; Railroad Creek flows southwesterly from a divide in Hurley River valley; Joffre Creek flows from a...
divide in Cayoosh Creek valley; and streams tributary to Birkenhead River flow from divides along Seton River valley. Mid-valley drainage divides are also present west of Lillooet River. All are located within 30 km of Lillooet River valley.

Smaller valleys throughout the study area delineate a dendritic drainage pattern that is distinct from the large valleys of southeast or northeast trend. The pattern is especially well developed south of Stein River between Harrison Lake and Fraser River (Fig. 3). The valleys are relatively short and curvilinear in plan, with depths of 0.5 to 1.2 km and valley bottom widths of 0.5 to 1 km. They are commonly U-shaped and have cirques, horns and arêtes in their headwaters. The well-spaced, dendritic planform pattern is similar to drainage patterns developed on gentle slopes or bevelled surfaces of uniformly resistant rock (Schumm et al., 2000). The modern low-order stream network shown in Figure 2 closely follows the dendritic valley pattern.

**Geological Constraints on Valley Age**

Constraints on valley age come from published geological and structural studies. The maximum age of a valley is the age of the youngest incised rocks or structures. The minimum age of a valley is either the age of the oldest rocks deposited within it or the age of the oldest crosscutting structures.

Bridge and Seton river valleys are incised into Jurassic to Late Cretaceous plutonic rocks. Both valleys trend across the Downton Creek Fault with no apparent offset. Thus, they must postdate the fault and have a maximum age of latest Cretaceous.

The oldest rocks deposited within Bridge River valley are Eocene fluvial sediments located north of Carpenter Lake. The Eocene fluvial sediments occur at an elevation of 840 m and are in depositional contact on Paleozoic bedrock (P. Schiarizza, pers. comm., 2001). Quaternary, or possibly Tertiary, strata occur at an elevation of 685 m and consist of silica-cemented fluvial gravels and sands deposited by northeast-flowing streams. A fossil willow leaf was found in sandy talus shed from the outcrop. Unfortunately, the source stratum could not be found. Finer facies were sampled for palynological analysis, however, the samples collected were barren. Although Seton River valley contains no mapped valley deposits older than Quaternary, it is interpreted to have the same age bounds as Bridge River valley by virtue of its proximity and
similarity of size and trend. The minimum age of Bridge and Seton river valleys is interpreted to be Eocene.

A minimum Eocene age for the valleys also is suggested by crosscutting structures. Both Bridge and Seton river valleys become parallel to, and are eventually truncated by, northwest-trending strike-slip faults. For example, west of Gold Bridge, Bridge River valley is up to 5 km wide and trends toward the northeast. East of Gold Bridge, the valley progressively narrows and turns to the east, and then to the southeast, parallel to the trend of Marshall Creek, Mission Ridge Fault and Yalakom Fault. The valley then turns again to the northeast and crosses the trace of the Marshall Creek Fault. Downstream from this point, Bridge River flows in a narrow, rock-walled canyon 250 to 400 m wide and up to 1800 m deep. The canyon traces a highly sinuous meander for a distance of about 15 km until joined by Yalakom River, then it flows along the trace of the Yalakom Fault to Fraser River. Similarly, the trend of Seton River valley changes from northeast to southeast as it approaches the Marshall Creek and Mission Ridge faults. Upon crossing the faults, the valley then narrows to a gorge less than 1 km wide, which is graded to the level of Fraser River.

Such changes in river direction and valley morphology occur when antecedent rivers cross active faults or regions of uplift (Schumm et al., 2000). West and southwest of Gold Bridge, the morphology of Bridge and Seton river valleys dates back to latest Cretaceous to Paleocene time. East of Gold Bridge, ancestral rivers were diverted by strike-slip faults and the resulting valley trends and morphology were formed in Eocene time.

There are fewer lithological controls on the age of other large northeast-trending valleys. Cayoosh Creek and Nahatlatch River valleys are incised into Jurassic to Late Cretaceous intrusions and older rocks. They are interpreted to be younger than Bridge and Seton river valleys because of their smaller size and lineament-controlled trends. These observations suggest a maximum valley age of Paleocene. The oldest deposits within the valleys are glacial sediments, giving a minimum age of Quaternary.

Stein River valley has a similar size and orientation to Cayoosh Creek and Nahatlatch River valleys and is probably of the same age. Stein and Nahatlatch river valleys appear to be continuous across the Fraser Fault with the valleys of Thompson River and Ainslie Creek – Nicoamen River (Fig. 3). If this interpretation is correct, Stein and Nahatlatch river valleys must postdate the fault, giving a maximum valley age of
Eocene. However, Stein River has incised through Miocene volcanic rocks, suggesting a maximum valley age of Miocene. It is possible that the Miocene volcanic rocks along Stein River provide a minimum age, but it is not known if these rocks are valley-filling deposits.

A maximum Paleocene age for Lillooet River valley is based on the fact that it follows the trace of, and therefore postdates, the Late Cretaceous Owl Creek, Fire Creek and Harrison Lake faults. It also truncates and postdates Bridge and Seton river valleys. However, Lillooet River valley exposes Miocene granodiorite, which suggests a younger maximum age. The granodiorite, 20 km south of Lillooet Lake, requires a minimum of 2000 m of incision after Miocene time. A minimum Quaternary age for Lillooet River valley is based on glacial deposits.

Assuming valley size correlates with valley age, the dendritic pattern must be younger than the northeast- or southeast-trending patterns. The youngest rock type incised by the dendritic valleys is the early Miocene Mount Barr granodiorite, dated at 19 Ma (Monger and Journeay, 1994) and located 20 km southwest of Hope (Fig. 2). Relief within this pluton requires a minimum of 1250 m of incision after early Miocene time. The oldest rocks deposited within the dendritic valleys are Pleistocene and Holocene volcanic flows and associated deposits of the Garibaldi Group (Green et al., 1988). The age of the dendritic valley pattern is thus bracketed between Miocene and Pleistocene time.

**Discussion**

Unequivocal evidence of landform inheritance is the presence of mid-valley drainage divides and natural lakes in long, bedrock-walled valleys. Neither of the underfit streams flowing in opposite directions along a contiguous bedrock valley could have carved the valley it occupies. Nor could lakes, which passively form when water pools in topographic lows, have formed the valleys they occupy. Such drainage anomalies along Bridge and Seton rivers indicate the valleys delineate a relict drainage network.

Evidence for the fluvial origin of the relict valleys is their obliquity to the regional geologic grain and the presence of Tertiary fluvial sediments within them. The paleoflow direction is interpreted to be towards the northeast on the basis of paleocurrents.
observed in suspected Tertiary fluvial strata, and of branching valley patterns observed at the junction of Bridge and Hurley rivers, and at the west end of Anderson Lake.

Eocene and Miocene granodiorites are exposed at the east end of Carpenter and Seton lakes, and within Lillooet and Stein river valleys. This seems to contradict the inferred latest Cretaceous to Eocene maximum ages of the valleys, but dating studies show parts of the Coast Mountains experienced significant regional uplift during Miocene to Pliocene time. Apatite and zircon fission track studies in the southern Coast Mountains by Parrish (1983) reveal a period of rapid apparent uplift from about 45 to 35 Ma, followed by very slow uplift from 30 to 10 Ma, and a final period of rapid apparent uplift of 2 to 3 km from about 10 to 2 Ma. Apatite (U-Th)/He ages in the northern Coast Mountains reveal a similar uplift history: little to no exhumation from before 30 Ma to 10 Ma; a higher, but still low, rate of exhumation from 10 to 4 Ma; followed by a period of rapid exhumation, on order of 1 km, starting 4 Ma ago (Farley et al., 2001). Given the well-documented episode of Miocene-Pliocene regional uplift, incision through Eocene and Miocene rocks must have occurred in the history of the valleys and does not affect their maximum age.

Preliminary interpretations suggest that the modern south-flowing Fraser River in the region from Lillooet to Hope is a relatively young feature. The modern river follows the trace of the Eocene Fraser Fault and therefore must postdate it. However, valley patterns suggest that at one time ancestral Stein and Nahatlatch rivers flowed northeastward across the fault trace. This implies that a south-flowing Fraser River postdates the ancestral Stein and Nahatlatch rivers and significantly postdates the development of the Fraser Fault.

**Drainage Network Reconstruction**

Figure 5 presents inferred drainage patterns in southwestern British Columbia during four time intervals in the Tertiary. The reconstructions are based on the interpretation of geomorphic and geological relationships, and are tentative as some valleys do not have good constraints on their age.

The first panel represents the inferred drainage network at some time between latest Cretaceous and Eocene time, before the onset of strike-slip faulting (Fig. 5A). Ancestral Bridge and Seton rivers flowed northeast across the southeastern Coast Mountains and across the future traces of the Fraser and Yalakom faults. Their
headwaters extended west of Lillooet River valley and likely drained an ancestral Coast Mountains in the southwest.

The second panel represents drainage patterns during Eocene time when the Yalakom and Fraser faults were active (Fig. 5B). Fault-induced relief forced formerly northeast-flowing ancestral rivers towards the east and southeast along the traces of the faults. Eventually, the rivers were able to cross the faults and resume their northeasterly direction. Ancestral Lillooet River valley captured the headwaters of ancestral Bridge and Seton rivers.

The third panel depicts drainage patterns during Oligocene time after the cessation of strike-slip faulting (Fig. 5C). The valleys of Cayoosh Creek, Stein River and Nahatlatch River were carved by ancestral streams flowing toward the northeast. The latter two continued across the trace of the Fraser Fault. Ancestral Bridge and Seton rivers also may have flowed northeastward across the trace of the Fraser Fault. Ancestral Lillooet River and other streams exploited lineaments and enlarged their drainage basins.

The last panel depicts drainage patterns during Miocene time prior to the onset of rapid uplift in Miocene time (Fig. 5D). Streams elaborated and elongated their networks. Ancestral Fraser River probably flowed southward along the trace of the Fraser Fault. Rapid uplift in late Miocene-Pliocene time caused all streams to incise their valleys.

**Conclusions**

Geomorphic evidence suggests that ancient drainage networks are preserved in the landscape of the southern Coast Mountains. They are delineated on the basis of drainage anomalies and valley trends, and dated by lithological and structural controls.

The oldest valleys preserved are those of ancestral Bridge and Seton rivers, which flowed northeasterly sometime between the latest Cretaceous and Eocene. They progressively narrow and change their trend to the southeast as they approach strike-slip faults of Eocene age near Lillooet. The stream patterns indicate rivers were already established prior to faulting and were deflected by the faults. It is possible that the eastern extensions of these valleys can be identified and used as piercing points to estimate displacement across Fraser and Yalakom faults.
Lillooet River valley crosscut ancestral Bridge and Seton rivers and captured their headwaters. Stein and Nahatlatch river valleys continued across the Fraser Fault, indicating a post-Eocene age for the valleys and suggesting that a northeast-dipping regional slope was maintained after Eocene strike-slip faulting. In Oligocene and Miocene time, a dendritic network of streams was superimposed on the older drainage patterns. Southward flow along the Fraser Fault between Lillooet and Hope was probably established after Miocene time.

Regional uplift during late Miocene-Pliocene time caused all streams to incise their valleys. During Quaternary time, valleys were widened and deepened by glaciation. Although drainage rearrangement may have occurred on a local scale due to thick glacial deposits and postglacial landslides, the modern drainage pattern throughout the southern Coast Mountains is much the same as it was in Miocene time.

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Figure 2. Location map of study area showing towns, streams, lakes and the distribution of Cenozoic rocks. Digital stream, lake and geology data from Journeay and Monger (1998).
Figure 3. Shaded relief map of study area illuminated from the northwest, showing the locations of valley-floor drainage divides and faults. Fault data from Journeay and Monger (1998).
Figure 4. View westward along Seton Lake from Highway 99 approximately 7 km west of Lillooet. Train at lower right provides scale.
Figure 5. Reconstructed drainage networks during: A, latest Cretaceous to Eocene; B, Eocene; C, Oligocene; and D, Miocene time.
CHAPTER THREE
PHYSIOGRAPHY AND TERTIARY BASE LEVELS IN SOUTHERN INTERIOR PAU AND ADJACENT AREAS, SOUTHWESTERN BRITISH COLUMBIA

Abstract

Geomorphology, valley-fill geology and drainage anomalies indicate that a suite of early Tertiary and older valleys exist in the southern Interior Plateau of British Columbia. In North Thompson River valley, relief and base level in the Eocene were the same as today, 1000 m and 400 m, respectively. This valley is older than middle Eocene. Thompson River from Kamloops to Martel follows the trend of a broad Eocene valley and is inset 125-350 m below the sub-Eocene unconformity. Thompson River valley from Martel to Lytton, and Nicola, Nahatlatch and Stein river valleys define a branching, northeast-flowing drainage pattern that postdates the Eocene Fraser Fault. Nicola Lake valley is probably Paleocene to Eocene in age. The area along Fraser River valley about 12 km south of Anderson River is a former drainage divide. Base level in Miocene time was about 500 m higher than in Eocene time.

Introduction

An intricate network of valleys is carved into the landscape of the southern Interior Plateau, British Columbia. Many valleys are poorly drained by underfit streams and lakes, and contain a stratigraphic record of Cenozoic fluvial and lacustrine deposition. Many tributaries to Fraser River have gentle upper reaches that change to steep, narrow canyons before joining the main stream. This is the opposite of an equilibrium longitudinal profile and suggests that base level has changed in the past. This paper describes the physiography of the area and examines geomorphic evidence of former base levels. Ages are assigned to some of the larger valleys based on geological and structural relationships.

Previous Work

Previous work on paleodrainage in the study area is limited and mostly consists of short sections in bedrock and Quaternary geology reports. Uglow (1923) described Eocene fluvial sediments on the floor of North Thompson River valley below Clearwater
and concluded the valley must be Eocene in age or older. Rice (1947) concluded that the modern drainage system in the Princeton area developed in late Pliocene or early Pleistocene time and that drainage rearrangement in the area was the result of glaciation. Trettin (1961) mapped an elevated floodplain near Pavilion that might be a former valley of Miocene Fraser River. Campbell and Tipper (1971) suggested the North Thompson – Clearwater River valley and other major drainage systems in southwestern British Columbia were established before Eocene time. Fulton (1975) suggested the valleys of Nicola River and Thompson River are antecedent and date back to early Tertiary or possibly Cretaceous time. He interpreted Nicola Lake valley as a Tertiary feature that was exhumed during the late Tertiary and Quaternary. Bevier (1983) thought Fraser and Chilcotin rivers established their modern courses in late Miocene time, whereas Mathews (1989) thought modern Fraser River was established possibly as recently as the late Pleistocene. Read (1988a) mapped a Miocene drainage network near Bonaparte and Deadman rivers that drained north and west. Tribe (2002) described an eastward-flowing paleodrainage network in the southern Coast Mountains that predates Eocene strike-slip faulting along the Fraser Fault.

Data Sources

Shaded relief maps, slope maps, topographic profiles and elevations were produced from 1:250 000-scale, 25-m gridded DEMs available from Base Mapping and Geomatic Services, British Columbia Government, using ArcView and ArcINFO software on a personal computer. Aerial photo interpretation of Fraser, Thompson and North Thompson river valleys was done with 1:50 000-scale aerial photographs. Stream and other geographic names are from 1:50 000- and 1:250 000-scale topographic maps. Geology is from Journeay and Monger (1998) and Journeay and Williams (1995).

Study Area

The study area extends from 49°15’N to 51°30’N and from 120°W to 122°W, and is drained mostly by Fraser River and its tributaries (Fig. 6). The longitudinal profile of Fraser River (Fig. 7) has a fairly smooth, gentle gradient downstream to Leon Creek, which is located just outside the northwest corner of the study area and which marks the first major step or knick point in the profile. Downstream from Leon Creek, and within the study area, the profile has a series of steps with steep gradients. The longitudinal profile of Thompson River has a gentle gradient from Kamloops to Bonaparte River (Fig.
8). Downstream of Bonaparte River, the profile is stepped with knick points and steep gradients. The southeastern part of the study area drains towards the southeast into Okanogan River via Similkameen River.

Geology and Structure

East of Fraser River, bedrock consists of north- and northwest-striking Paleozoic to Jurassic rocks of the Quesnellia, Cache Creek, Tyaughton–Methow and Bridge River terranes. West of Fraser River, bedrock is dominated by Jurassic to Late Cretaceous intrusions of the Coast Plutonic Complex. The area last experienced submarine deposition in the Jurassic, and since then, has been the site of restricted sedimentary deposition and widespread volcanism. Cretaceous Spence Bridge Group volcanic rocks crop out in a northwest-trending belt that overlaps the Quesnellia and Cache Creek terranes. Paleozoic and Mesozoic rocks constitute the bedrock into which the valleys are incised and are described in detail by Monger (1989), Journeay and Monger (1994), and others.

Small outcrops of Tertiary sedimentary strata, which record fluvial and lacustrine environments, are scattered throughout the area (Fig. 9, Table 1). These strata are locally overlain by extensive volcanic flows and breccias of the Eocene Kamloops Group. Miocene fluvial sediments were deposited in valleys up to 500 m deep in the upper Bonaparte River area (Read, 1988a). Horizontal Miocene-Pliocene Chilcotin basalts crop out in the northern part of the study area and are dated at 9-15 Ma (Mathews, 1989). During the Quaternary, the area experienced repeated glaciation (Clague, 1989) and minor basaltic volcanism.

Major faults in the area include the northwest-striking Hozameen Fault, which was offset by north-northwest-striking Fraser Fault. Fraser Fault had an estimated 80-140 km or more of dextral strike-slip displacement between 47 Ma and 35 Ma (Monger and Journeay, 1994). North-northwest-striking strike-slip faults occur on Thompson Plateau (Monger, 1985).

Physiography

The physiography of the area was described first by Bostock (1948) as the Southern Plateau and Mountain area. Holland (1976) delineated the Coast Mountain, Cascade Mountain and Interior Plateau physiographic provinces, and subdivided the last
into the Thompson Plateau, Fraser Plateau, Clear Range and Marble Range (Fig. 6). Mathews (1986) renamed the Fraser Plateau the Cariboo Plateau, and combined Clear and Marble ranges into the Pavilion Range. These classifications are presented at 1:2 000 000-scale or smaller. Fulton (1975) subdivided the Nicola-Vernon area into uplands, midlands and valleys at a map scale of 1:500 000.

The physiographic map produced for this study (Fig. 9) delineates areas of similar geomorphology, relief, slope and drainage identified on 1:500 000-scale shaded relief maps. At the broadest scale, the landscape is classified into mountains, highlands, plateaus, midlands and valleys, designated by upper-case letters. These categories are adapted from Fulton (1975) and correspond to the tertiary level of classification of Bostock (1948). Further subdivision is made on the basis of surface texture or pattern and degree of drainage development, designated by one or more lower-case letters. Major landform types are described below.

Mountains (R) are regions of high to moderate relief with steep slopes, a rugged profile and a restricted area at or near the summit elevation. Highlands (H) are elevated regions of moderate relief with moderate to gentle slopes, a rounded outline and a large area at or near the summit elevation. Highlands have a sparser stream network than mountains, but may contain broad valleys or canyons. Plateaus (P) are extensive, elevated regions of low relief with most of the area at or near the summit elevation. Commonly, they have poorly developed drainage, but may contain local canyons or deep valleys. Midlands (M) are areas of moderate to low relief elevated above local base level but below adjacent mountain or highland summits. Midlands represent elevated former valley floors (Fulton, 1975) and may contain canyons, valleys, rock benches or terraces. Valleys (V) are elongate, relatively narrow depressions bounded by rock slopes. They generally contain a stream with an outlet, but some contain multiple streams or lakes. Only the largest valleys are delineated on Figure 9.

Mountains predominate in the western and southwestern parts of the study area and correspond closely to the Coast Mountain physiographic province of Holland (1976). Holland’s Cascade Mountain physiographic province is subdivided in Figure 9 into a western belt of deeply incised mountains (Rd) and an eastern belt of less-incised mountains (Ri) and incised highlands (Hi). Holland’s Clear Range is subdivided into a southern mountain region (Ri) and a northeastern highland region (H). Highlands continue across Pavilion Lake into the southern Marble Range. Remnants of a
peneplain observed in northern Marble Range may represent a northward extension of highlands. Midlands fringe the largest valleys in the region and are inset into the highlands and plateaus.

The terrain around Ashcroft (Ms) consists of an unusually wide, rock-floored valley interpreted to be a strath. A strath is a terrace-like remnant of a broad valley floor formed by lateral stream erosion that has undergone subsequent incision following uplift (Bates and Jackson, 1987). Hat and Botanie creek valleys (Mm) consist of fairly flat, smooth terrain with little stream incision surrounded by highlands to the east and west.

**Geomorphic Evidence of Former Base Levels**

Many valleys in the study area are drained by two underfit streams flowing in opposite directions from a low divide on the valley floor (Fig. 9). The valley-floor divides range from 400 m to 1500 m elevation with maxima around 650 m, 800 m, and 1050-1150 m (Figs. 10, 11). Eocene sedimentary strata outcrop from about 400 m to 800 m elevation. The average elevation of the base of Miocene strata is about 900 m.

Topographic profiles across Thompson River valley show a broad rock bench in Triassic and older bedrock, on which Eocene sediments and volcanic rocks were deposited. At Kamloops, the bench has a minimum elevation of about 450 m on the south shore of Kamloops Lake and rises to about 750 m to the south (Fig. 12, B-B' ). The bench is at least 150 m above the level of Kamloops Lake, which is up to 150 m deep (Fulton, 1975). At McAbee, the bench is 480-515 m elevation, and 125 m above the river (Fig. 12, C-C' ). Downstream, the rock bench widens and merges with the Ashcroft strath.

The floor of the Ashcroft strath is 900 m in elevation in the west and slopes gently to 650 m elevation at the river (Fig. 12, D-D' ). East of the river, the strath floor is 480-680 m elevation. Above the strath and to the east, the sub-Eocene unconformity rises steeply to 1300 m in the highlands. The strath floor is 200-350 m above the river. The sub-Eocene unconformity has 800 m of relief in this area.

The rock bench is not present in North Thompson River valley (Fig. 12, A-A' ). Here, Eocene sediments crop out between 410 m and 570 m elevation, close to modern river level. The strata are 600 m below the west valley wall and 1100 m below the east valley wall. The sub-Eocene unconformity has 1000 m of relief in this area.
Many tributary streams flow in relatively wide, gently sloping valleys that become narrow, steep rock canyons near their junction with Fraser River (Fig. 13). The valleys are unusual because they are graded in their upper and middle reaches, not in their lower reaches as is typical of a stream in equilibrium. Graded valleys are widespread west of the river. The minimum elevations of graded reaches along the east and west walls of the Fraser River valley are shown in Figure 14. West of the river, low-order tributaries between Seton River and Nahatlatch River are at 1300-1500 m elevation. South of Nahatlatch River, the low-order graded reaches decrease to about 500-900 m elevation. East of Fraser River, graded valleys are scarce north of Thompson River junction. South of this junction, graded valleys are more common and range in elevation from 800 to 1200 m.

Discussion

Base level of erosion is the level below which streams cannot erode their channels (Bates and Jackson, 1987). It is a hypothetical surface that matches sea level along the coast, where it is called ultimate base level, and rises inland along principal streams and their tributaries. In aggrading areas, local base level is the depositional surface. A graded stream is one that has adjusted its bed to a local base level and has no rapids or waterfalls along its course. Valley-floor divide elevations may approximate former base levels.

The grey dashed line in Figure 14 joins the downstream limits of graded valleys and approximates a former base level. Principal streams tend to have a lower elevation than first- or second-order streams because of their larger drainage area and capacity to erode their bed. The extent of graded valleys in Figure 13 closely matches the extent of the Miocene-age drainage network described by Tribe (2002).

The floor of the Ashcroft strath is interpreted to represent an old base level stillstand. Displacement of Thompson River to the east of the strath valley axis may indicate relative uplift in the west. The change in elevation of the sub-Eocene surface from 400 m at Chu Chua and 450 m at Kamloops and McAbee, to 600 m on the Ashcroft strath, may also reflect relative uplift in the Hat Creek area west of the strath. The Ashcroft strath has a similar orientation, size and shape to nearby Hat Creek valley. Another strath occurs farther west in the Coast Mountains near Gold Bridge (Tribe, 2002).
The smooth topography of the floor of Hat Creek valley is interpreted as the surface expression of a filled depositional basin. Hat Creek valley contains over 1000 m of coal-bearing lacustrine and fluvial sediments that were deposited in a graben whose base level was controlled by a spillway (Church, 1975). Four candidate spillways are shown in Figure 9 by drainage divides in the highlands bordering the valley. The divides have different elevations and probably served as spillways at different times. The valley containing Pavilion Lake and Creek was probably the main spillway in the Miocene, as suggested by Miocene fluvial strata near Pavilion townsite. Base level indicators in structurally controlled Hat Creek valley do not necessarily relate to base levels elsewhere. This is also true in Fraser River valley where most Tertiary strata are fault-bounded.

The apparent alignment of Nahatlatch River with Mowhokam Creek valley, and Stein River with lower Thompson River is intriguing. Figure 14 shows the graded floor of Stein River to be about 500 m elevation, the same as the rock bench at Botanie Creek, which is used as a proxy for the graded floor of Thompson River. The upper reach of Mowhokam Creek is a broad, graded valley with a valley-floor divide from which Nicoamen River flows northward along gentle gradients, then over a 200 m waterfall before joining Thompson River. Figure 14 shows that the graded floor of Nahatlatch River is about 325 m elevation, whereas the graded limit of Mowhokam Creek is 1000 m, and the Mowhokam divide is 1280 m. The difference in elevation of the graded limit of Mowhokam and Nahatlatch valleys may reflect 700 m of uplift of the land east of Fraser River and south of Thompson River. Alternatively, it may reflect the ability of east-flowing Nahatlatch River to incise its bed in concert with base level lowering along Fraser River, whereas the beheaded stream that flowed along Mowhokam-Nicoamen valley was unable to incise its bed and was stranded at high elevation.

Glacial erosion may be partially responsible for the development of graded valley reaches along tributaries west of Fraser River, and for the valleys in the deeply incised mountains (Rd) north and east of Hope (Fig. 9). Many of these valleys have a fairly constant downstream width, which suggests alpine glaciers have truncated spurs and straightened the valleys.
Estimates of Valley Age and Tertiary Base Levels

North Thompson River valley incises Mesozoic and older rocks and contains a record of middle Eocene lacustrine and fluviatile deposition. The valley follows the trace of Jurassic to Eocene faults (Journeay and Monger, 1994). It was 1000 m deep in the middle Eocene and thus may have formed several million years earlier. Local base level in middle Eocene time was similar to today, about 400 m elevation. An ancestral stream probably flowed northwest or southeast along Louis Creek Fault. It was captured at a point 25 km south of Chu Chua by an ancestral stream flowing south along lower North Thompson River valley. Today, North Thompson River valley is being filled with postglacial deposits.

Thompson River from Kamloops to Martel incises Mesozoic and older bedrock and is filled with lacustrine, fluviatile and volcanic deposits of Eocene age. The sub-Eocene unconformity in this area is expressed as a broad depression coincident with the trend of the river. Kamloops Lake and Thompson River are inset into the floor of this depression. The modern river has eroded through the Quaternary fill and flows close to the underlying bedrock surface. Cumulative post-Eocene incision is 125-350 m. The broad profile of the sub-Eocene unconformity suggests that the valley is older than Eocene.

From Martel to Lytton, Thompson River flows through Cretaceous Spences Bridge Group volcanic rocks and is fault-controlled in places. No midlands are found in this valley, which has single-slope walls from river level to the ridge tops (Fig. 12, E-E’). The valley does not appear overly wide for the modern Thompson River. It must be younger than the upstream segment, which comprises the Ashcroft strath, because of its smaller size and the absence of a rock bench. Today, Thompson River has eroded through Quaternary fill and is carving a narrow notch in the underlying bedrock. Nicola, Nahatlatch and Stein river valleys have the same dimensions as this segment of Thompson River valley. If they are the same age, these valleys define a north-flowing river system that postdates the Eocene Fraser Fault because they are not offset across it.

The Paleocene Nicola Horst forms the northern wall of Nicola Lake. Other parts of the valley are in older rocks. Eocene fluviatile and lacustrine sediments occur within the valley. Nicola Lake valley is probably Paleocene to Eocene in age. Today, it is being filled with postglacial deposits.
Nicola River valley from Canford to Spences Bridge is incised in Cretaceous volcanic rocks. It appears to be red to the north-trending Lomex Fault (Journeay et al., 2000a) that extends along longitude 121°W. The fault marks the place where the Nicola Lake valley narrows, and where the broad valley located at latitude 50°N, longitude 121°W is truncated to the west (Fig. 9). The change in character of the valleys across the fault suggests east-side-down displacement, although Journeay et al. (2000a) show this fault as west-side-down. Nicola River valley must therefore postdate the Lomex Fault.

Near Lillooet, Fraser River valley reaches its greatest width of 5 km. The river formerly flowed along Cinquefoil valley at about 900 m elevation. Fraser River valley is narrowest, less than 500 m wide, in the 12 km reach south of Anderson River. Graded tributary valleys on the east side of the river show a branching stream network made up of Anderson and East Anderson rivers and Uztlius Creek. The lower north-northeast trending reach of Anderson River follows the trace of the Hozameen Fault. This area may be an old drainage divide, and the youngest segment of Fraser River valley. Modern Fraser River has incised through the Quaternary and Tertiary fill and is eroding a rock notch in the bottom of the valley in this area.

Conclusions

Geomorphology, valley-fill geology and drainage anomalies indicate that a suite of early Tertiary, and possibly older, valleys exist in southwestern British Columbia. Drainage anomalies, such as valley-floor divides, underfit streams and graded valley segments, point to former base levels stranded in the landscape. The valleys of North Thompson River and Thompson River from Kamloops to Martel are possibly Paleocene or Late Mesozoic in age. Hat Creek and Nicola Lake valleys are Eocene in age. Lower Thompson River, Nahatlatch River, Stein River and Mowhokam Creek formed after the Eocene.

Acknowledgments

Base Mapping and Geomatic Services, Ministry of Sustainable Resource Management provided the 25-m, gridded digital elevation data. John Clague and Robert Turner reviewed the manuscript. This work was supported by an NSERC scholarship,
NRCan Earth Sciences Sector supplement, SFU Graduate Fellowship and Clague's NSERC Research Grant.
Figure 6. Map of the study area showing towns, streams, lakes and physiographic provinces.
Figure 7. Longitudinal profile of Fraser River from Prince George to Hope. The reach from Pavilion Creek (km 430) to Coquihalla River (km 630) is in the study area.
Figure 8. Longitudinal profile of Thompson River from Kamloops to Lytton.
Figure 9. Physiographic map of the study area showing locations of Tertiary sedimentary rocks (Table 1), valley-floor drainage divides, cross-sections and volcanic forms.
Figure 10. Histogram of elevations of valley-floor divides (n = 74). Divide locations are shown in Figure 9.
Figure 11. Scatter plot of elevations of valley-floor divides and base of documented Eocene and Miocene sedimentary strata. Divides are grouped by regions shown in inset map. Valley-floor divides from the southern Coast Mountains outside of the study area are also included.
Figure 12. Topographic profiles of North Thompson and Thompson River valleys showing schematic geology. Profile locations are shown in Figure 9. Geology legend: Es, Eocene sediments; Kv, Cretaceous volcanic rocks; Q, Quaternary glacial deposits; TrN, Triassic Nicola Group volcanic rocks. Vertical exaggeration = 3.4.
Figure 13. Map showing the extent of graded valley reaches along tributaries of Fraser River south of Lillooet.
Figure 14. Profiles of the east and west walls of Fraser River valley showing the minimum elevation of graded valley reaches mapped in Figure 13.
Table 1. Tertiary sedimentary strata in the study area (Fig. 9, stars).

<table>
<thead>
<tr>
<th>No.</th>
<th>Age, Formation</th>
<th>Location</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Eocene, Hat Creek Beds</td>
<td>Hat Creek</td>
<td>Basal Coldwater beds are 1300 m of fluvial conglomerate and sandstone. Overlying Hat Creek Coal Fm. is 300 m of coal, claystone, sandstone, conglomerate and ash deposited in marsh and lacustrine settings. Medicine Creek Fm. is 600 m of siltstone and claystone. Hat Creek basin is a fault-bounded graben. Elevation 860 m to 1207 m.</td>
<td>Church, 1975</td>
</tr>
<tr>
<td>4</td>
<td>Eocene, Coldwater Beds</td>
<td>Nicola Valley</td>
<td>Up to 230 m of basal conglomerate, breccia, sandstone, shale and coal. Elevation 616 m to 850 m.</td>
<td>Cockfield, 1961</td>
</tr>
<tr>
<td>7</td>
<td>Mid-Eocene, Tranquille Fm.</td>
<td>Kamloops Lake</td>
<td>Up to 500 m of tuffaceous sandstone, siltstone, and minor conglomerate. Bedding dips 0° to 35°. Lacustrine paleoenvironment. Elevation 376 m to 567 m.</td>
<td>Graham and Long, 1979; Ewing, 1981</td>
</tr>
<tr>
<td>8</td>
<td>Eocene, McAbee Beds</td>
<td>McAbee-Savona</td>
<td>Mudflow, flow breccia and 130 m of lacustrine deposits. Elevation 500 to 800 m.</td>
<td>Ewing, 1981</td>
</tr>
<tr>
<td>11</td>
<td>Mid-Eocene, Princeton Group</td>
<td>Princeton</td>
<td>Sandstone, siltstone, coal seams and minor conglomerate. Elevation 640 m to 1094 m.</td>
<td>Preto, 1979</td>
</tr>
<tr>
<td>12</td>
<td>Eocene, Allenby Beds</td>
<td>Hope</td>
<td>Nonmarine cobble conglomerate and minor sandstone deposited in a graben along Fraser Fault. Strata are folded with subvertical dips, bounded on the west by Hope Fault, on the east by a vertical unconformity on gneiss. Elevation 185 m to 582 m.</td>
<td>Monger, 1969</td>
</tr>
<tr>
<td>1</td>
<td>Middle Eocene, unnamed</td>
<td>Siwhe Creek</td>
<td>1000 m of fault-bounded, basal breccia, conglomerate, sandstone, shale. Fluvial paleoenvironment. Strata tilted and displaced by Fraser Fault. Elevation 294 m to 942 m.</td>
<td>Duffell and McTaggart, 1952</td>
</tr>
<tr>
<td>No.</td>
<td>Age, Formation</td>
<td>Location</td>
<td>Description</td>
<td>Reference</td>
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</tr>
<tr>
<td>14</td>
<td>Eocene, Princeton Group</td>
<td>Princeton</td>
<td>Up to 300 m of conglomerate, sandstone, shale and coal. Strata are horizontal but have steep dips in places. Elevation 640 m to 1094 m.</td>
<td>Rice, 1947</td>
</tr>
<tr>
<td>15</td>
<td>Eocene, unnamed</td>
<td>Kingsvale</td>
<td>Up to 2000 m of conglomerate and sandstone deposited by north-flowing braided streams in the Fig Lake Graben. Strata dip 25° to 40°. Elevation 761 m to 1211 m.</td>
<td>Thorkelson, 1989</td>
</tr>
<tr>
<td>16</td>
<td>Eocene, Allenby Beds</td>
<td>Princeton, Trapp Lk</td>
<td>No description available.</td>
<td>Journeay and Monger, 1994</td>
</tr>
<tr>
<td>6</td>
<td>Mid-Eocene, Chu Chua Fm.</td>
<td>Chu Chua</td>
<td>Up to 50 m basal conglomerate and 800 m of sandstone, shale and coal. Fluvial and lacustrine paleoenvironment. Elevation 410 m to 570 m.</td>
<td>Uglow, 1923; Campbell and Tipper, 1971</td>
</tr>
<tr>
<td>17</td>
<td>Eocene ?</td>
<td>Spences Bridge</td>
<td>Small exposure of lithic sandstone, argillite and coal. Coal seam is 2 m thick. Age control poor, but thought to be Eocene. Location of outcrop is uncertain.</td>
<td>Duffell and McTaggart, 1952</td>
</tr>
<tr>
<td>18</td>
<td>Eocene ?</td>
<td>Keatley Creek</td>
<td>Isolated exposure of well-indurated cobble conglomerate containing clasts of Cache Creek Group, Spences Bridge Group and Coast intrusions.</td>
<td>Duffell and McTaggart, 1952</td>
</tr>
<tr>
<td>5</td>
<td>Miocene, Deadman River Fm.</td>
<td>Deadman, Bonaparte Rivers</td>
<td>350 m of ash, sandstone, siltstone, shale and diatomite. Fluvial paleoenvironment in deeply incised, north- and west-trending valleys. Elevation of base 690 m to 1020 m.</td>
<td>Campbell and Tipper, 1971; Read, 1988b</td>
</tr>
<tr>
<td>2</td>
<td>Miocene-Pliocene, unnamed</td>
<td>Pavilion</td>
<td>Up to 60 m of horizontal or gently-dipping lithic sandstone, conglomerate and carbonaceous shale. Fluvial floodplain paleoenvironment. Elevation 970 m to 1212 m.</td>
<td>Trettin, 1961</td>
</tr>
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CHAPTER FOUR
EOCENE PALEO-PHYSIOGRAPHY AND DRAINAGE DIRECTIONS, SOUTHERN INTERIOR PLATEAU, BRITISH COLUMBIA

Abstract

A map of reconstructed Eocene physiography and drainage is presented for the southern Interior Plateau region, British Columbia. Eocene landforms are inferred from the distribution and depositional environment of Eocene rocks, and from cross-cutting relationships between regional-scale geomorphology and bedrock of known age. Eocene drainage directions are inferred from physiography, relief and base level elevations of the sub-Eocene unconformity, and the documented distribution, provenance and paleocurrents of early Cenozoic fluvial sediments. The Eocene landscape of the southern Interior Plateau resembled its modern counterpart, with highlands, plains and deeply incised drainages, except regional drainage was to the north. An anabranching valley system trending west and northwest from Quesnel and Shuswap Highlands, across Cariboo Plateau to Fraser River valley, contained north-flowing streams from Eocene to early Quaternary time. Other valleys dating back at least to middle Eocene time are those of North Thompson valley south of Clearwater, Thompson valley from Kamloops to Spences Bridge, the valley containing Nicola Lake, Bridge River valley, and Okanagan Lake valley. During the Cenozoic, highlands existed where the Coast Mountains are today. Southward drainage along the modern Fraser, Chilcotin and Thompson River valleys was established after the Late Miocene.

Introduction

The current model of physiographic evolution of the southern Interior Plateau calls for Late Cretaceous to early Eocene erosion and peneplanation, followed by episodes of regional uplift in middle Eocene and Pliocene time (Mathews, 1991). The Eocene landscape is described as an undulating land surface with few erosional remnants, resulting from prolonged subaerial erosion since at least Late Cretaceous time. Widespread calc-alkaline volcanic rocks of Eocene age and scattered sediments were deposited in extensional basins across this landscape (Tipper, 1971; Mathews, 1991).
The antiquity of parts of the present-day landscape has been recognized by geologists for over 100 years. A variety of observations support the existence of an ancestral Fraser River that drained northward from near Williams Lake to Prince George in the early Cenozoic: the gentle northward dip of the Interior Plateau from the International Boundary to Prince George; the pattern of stream junctions (acute angles closing to the north) north of Williams Lake; and northward paleoflow indicators in Cenozoic quartzite conglomerates within Fraser River valley (Dawson, 1895; Lay, 1940, 1941). Fraser and Chilcotin rivers probably established their modern southward courses in the Late Miocene or Pliocene, as rocks of this age form part of their valley walls (Bevier, 1983; Mathews, 1989). North Thompson – Clearwater River valley and other major drainage valleys in southwestern British Columbia were established before the Eocene (Campbell and Tipper, 1971), as evidenced by the presence of Eocene fluvial sediments on the floor of North Thompson valley 30 km south of Clearwater (Uglow, 1923). The valleys of Nicola, Thompson and Okanagan rivers are thought to be antecedent and to date back to Paleogene or possibly Cretaceous time (Drysdale, 1914; Duffell and McTaggart, 1952; Fulton, 1972, 1975). Nicola Lake valley is described as a Paleogene feature that was later exhumed (Fulton, 1975).

This study reconstructs Eocene landscape and drainage pattern in the southern Interior Plateau and provides estimates of that landscape's relief and base level elevation. It synthesizes published geological observations of others, with regional-scale geomorphic domains observed on high-resolution shaded relief maps. The paleophysiographic map shown here is a detailed, graphic depiction of physiography during Eocene time, and supports many of the conclusions reached by previous workers (Uglow, 1923; Lay, 1941; Tipper, 1971; Fulton, 1975; Mathews, 1991, Read, 2000).

**Data and Methods**

Hillshades, topographic profiles and other derivative maps were made from a 1:250 000-scale, 25-m gridded digital elevation model provided by British Columbia Ministry of Sustainable Resource Management. Most maps were generated using ArcView mapping routines on a personal computer. Bedrock geology is taken from geologic maps and reports of the Geological Survey of Canada and other workers. Digital geology is from Journeay and Monger (1998), Journeay and Williams (1995) and the British Columbia Geological Survey.
Modern Physiography and Drainage

The study area is the southern Interior Plateau from 118°W to 123°W and from 49°N to 53°N (Fig. 15). The Interior Plateau is a composite physiographic province comprising contiguous highlands and plateaus, including Thompson, Cariboo and Chilcotin plateaus, and Okanagan, Shuswap and Quesnel highlands (Fig. 15; Holland, 1976; Mathews, 1986). Shaded relief maps of the study area (Figs. 16, 17) clearly show the moderate- and low-relief highlands and plateaus bounded by the rugged, highly dissected terrain of the Coast and Cascade Mountains to the west, and the Selkirk, Monashee and Cariboo Mountains to the east.

Highlands and plateaus are dissected by valleys of differing size and orientation. Drainage is broadly south and southwest along Fraser, Thompson, Okanagan and Kettle rivers and their tributaries (Fig. 15). Exceptions to southward drainage are Shuswap River, which flows northwest through a series of lakes to South Thompson River, and Chilcotin and Similkameen rivers, which flow southeast. The rivers typically flow in broad or narrow, steep-walled valleys several hundreds of metres below the general level of the plateau surface. Many of the large valleys throughout the southern Interior Plateau contain naturally impounded lakes, valley-floor drainage divides and underfit streams. Poorly drained large valleys indicate that the modern-day stream drainage is not adjusted to the landscape, and that some valleys may be relicts from an earlier time (Tribe, 2002, 2003).

Bedrock Geology

Landscapes of the southern Interior Plateau are developed in Paleozoic to Jurassic volcanic, sedimentary, metamorphic and plutonic rocks (Fig. 15, white; Campbell and Tipper, 1971; Monger, 1989). The area underwent compressional and extensional deformation during the Paleozoic and Mesozoic along north-trending faults, such as the Okanagan Valley, Eagle River and Louis Creek faults (labelled on Fig. 15; Monger and Price, 1979; Monger et al., 1982; Brown and Journeay, 1987). Bedrock in the southern Coast Mountains is dominated by Jurassic to Late Cretaceous intrusions of the Coast Plutonic Complex with septa of older foliated, greenschist- and higher grade sedimentary and volcanic rocks. The southern Interior Plateau last experienced marine deposition in Jurassic time.
From the Cretaceous through the Eocene, the study area was the site of localized terrestrial deposition and widespread volcanism (Fig. 15; Mathews, 1991). The sub-Cretaceous unconformity is preserved in Thompson, Cariboo and Chilcotin plateaus, neighbouring Cascade and Paviiion ranges and the northeasternmost portion of the Coast Mountains in the study area, but has not been observed in the Okanagan Highland and at the eastern margin of the Interior Plateau (Fig. 15). The sub-Cretaceous unconformity is overlain primarily by Spences Bridge Group volcanic rocks. Scattered exposures of Cretaceous fluvial conglomerate and sandstone, some containing northward-directed paleocurrent indicators, are known in the western part of the study area (Schiarizza et al., 1997; Mahoney et al., 1999).

The sub-Eocene unconformity is preserved throughout the Interior Plateau, including the Okanagan Highland, but is missing from mountain ranges to the east and the Coast Mountains to the west (Fig. 15). Outcrops of Eocene fluvial and lacustrine sediments are scattered throughout the study area and are overlain by widespread volcanic flows and breccias of the Eocene Kamloops Group and correlative rocks (Fig. 15). In the Princeton area, Allenby Formation sedimentary strata of Eocene age are underlain by Eocene volcanic rocks of the Cedar Formation (Read, 2000).

Cretaceous and Paleogene rocks are offset by north- and northwest-trending, dominantly strike-slip faults (Fig. 15). These faults include the northwest-trending Yalakom and Hozameen faults of Late Cretaceous to Paleogene age (Schiarizza et al., 1997), and the cross-cutting Fraser Fault, which was active 47 to 35 Ma ago with 80-120 km of dextral strike-slip offset (labelled on Fig. 15; Monger, 1989; Coleman and Parrish, 1991). Normal and strike-slip faults on Thompson Plateau and Okanagan Highland, some with northeast or east strikes, are red to dextral strike-slip faulting and the development of grabens and half-grabens during Paleogene time (Fig. 15; Monger, 1985). Fraser River valley and parts of Okanagan Valley follow faults, but many other large valleys trend conspicuously oblique to mapped north- and northwest-trending faults, for example the valleys of Carpenter, Anderson and Pavilion lakes near Lillooet, and Thompson River near Kamloops. The obliquity of large valleys to mapped faults indicates the valleys are not fault-controlled, thus they may be fluvial in origin.

Sub-Miocene and younger unconformities (not shown in Fig. 15) are well preserved throughout the study area, including several sites in the Coast Mountains. Miocene fluvial strata were deposited in valleys up to 500 m deep (Read, 2000) in the
upper Bonaparte River area and occur at scattered locations on Okanagan Plateau
(Mathews, 1988). Flat-lying Miocene-Pliocene Chilcotin basalts are widespread on
northern Thompson Plateau and on Cariboo and Chilcotin plateaus, and Okanagan
Highland (Mathews, 1988, 1989). Pliocene basalt flows are confined to valleys in the
Merritt area and near Clearwater (Hickson, 1986). During the Quaternary, the area
experienced repeated glaciation (Clague, 1989) and minor volcanism (Souther, 1991).

**Geomorphology and the Eocene Rock Record**

The Eocene landscape is reconstructed by relating the distribution and
depositional environments of Eocene rocks to their regional physiographic setting. The
Eocene sedimentary record is one of areally restricted terrestrial deposition in rivers,
lakes and swamps (Table 2). The scattered exposures cannot be unequivocally
correlated except in the Princeton and Tulameen basins (Read, 2000). All Eocene
sedimentary rocks occur above a profound unconformity on Cretaceous or older bedrock
or, locally, on plutonic rocks of Paleocene age. An exception is the Hat Creek area
where Eocene sediments postdate the onset of Eocene volcanism (Read, 2000).
Although Eocene sedimentary rocks are, in places, tilted and bounded by faults, the
presence of coeval, widespread volcanic rocks argues against the sediments being
simply the down-dropped, preserved remnants of a formerly much more extensive
Eocene sedimentary unit (Tipper, 1971).

The distribution of Eocene sedimentary rocks is shown in Figures 16 and 17.
Eocene sedimentary rocks are almost exclusively found in large valleys or topographic
depressions (Figs. 16, 17, circles). Most valleys containing Eocene rocks exhibit one or
more drainage anomalies, such as underfit streams, valley-floor drainage divides, and
elongate, rock-walled lakes. For example, Thompson River from Kamloops to Spences
Bridge (Figs. 15, 16) flows along an unusually broad valley where it is first a natural lake
and then an underfit stream. It also contains fluvial and lacustrine sediments. The
association of Eocene fluvial, lacustrine and paludal deposits with poorly drained, large
valleys is evidence for the antiquity of the valleys.

Eocene or older constructional volcanic landforms, such as domes, shields and
cones (Table 3, Fig. 16), are additional evidence that the landscape retains some early
Cenozoic features. Volcanic landforms of Eocene age occur north of Kamloops Lake
and Ashcroft on northwestern Thompson Plateau (V5, V6 in Table 3, Fig. 16). Subaerial
erosion has altered and reduced, but not eliminated, the original volcanic form. Older volcanic remnants on southwestern Thompson Plateau near the Cascade Mountains and Pavilion Ranges suggest that landforms of Cretaceous age, and possibly older, persist (V1-V4 in Table 3, Fig. 16).

**Eocene Base Level and Relief**

Geologic relations and geomorphic setting are examined to determine base level, relief and drainage directions during the Eocene. Base level of erosion is the level below which streams cannot erode. It is a hypothetical surface that matches sea level along the coast and rises inland along principal streams and their tributaries. In aggrading areas, local base level is the depositional surface. Despite the fact that base level may be at different elevations over a large region, estimates of base level during the Eocene can be determined from the trends in elevation of preserved Eocene sediments (Figs. 18, 19), and from geologic cross-sections (Fig. 20). Cross-sections also show the configuration of the sub-Eocene unconformity and provide estimates of paleo-topographic relief (Fig. 20). The sub-Eocene unconformity represents the diachronous surface upon which Eocene sedimentary and volcanic rocks were deposited. Relief measured from cross-sections gives a minimum value for the relief of the sub-Eocene unconformity at the time of sediment deposition.

The elevation range of Late Cretaceous and Cenozoic sedimentary rocks and volcanic forms along four transects in the study area shows that Eocene rocks have the lowest position in the landscape (Figs. 18, 19). Eocene sedimentary rocks (Fig. 19, grey) range from 200 to 1400 m elevation, with most strata between 400 and 1200 m. Late Cretaceous to Paleocene strata are elevated several hundred metres above Eocene strata throughout the study area (Fig. 19), which suggests Eocene base level dropped with respect to earlier base levels. The drop in base level caused streams to incise into the older surface, producing significant topographic relief (Fig. 21).

In many places, Eocene relief was similar in magnitude and location to modern relief. Relief of 400-1000 m or more is seen in profiles across Thompson Plateau (Fig. 20). Fluvial and lacustrine sediments of the Eocene Chu Chua Formation crop out near modern river level in the valley of North Thompson River (site 6 in Table 2, Fig. 16), giving an estimate of 1300 m relief on the sub-Eocene unconformity (Fig. 20A).
hundred metres of paleo-relief on the sub-Eocene unconformity is reported near Cache Creek (Read, 1988a).

Near Horsefly Lake, middle Eocene volcanic and lacustrine rocks crop out in a valley that is 35 km wide and about 500 m deep, and is carved in Paleozoic and Mesozoic rocks (Fig. 20B). Eocene sediments (sites 9, 10 in Table 2 and Fig. 16) and Miocene Chilcotin basalts were deposited on the floor of the valley at 900-1000 m elevation. Quesnel Lake, Horsefly Lake and Horsefly River are located in this valley, about 200 m below the broad former valley floor. The coincidence of the sub-Eocene and sub-Miocene unconformities near Horsefly Lake (Fig. 20B) indicates that base level in this region has not changed significantly throughout the Cenozoic.

In the Princeton area, relief on the sub-Eocene unconformity is 400-800 m. The sub-Eocene unconformity delineates a broad valley or basin about 15 km wide and at least 400 m deep, in which Eocene volcanic and sedimentary rocks of the Princeton Group (sites 13, 14 in Table 2, Fig. 16) were deposited. Nearby, to the northwest and southeast, the sub-Eocene unconformity rises in elevation and parallels the plateau surface at about 1300 m elevation (Fig. 20C).

In the Kamloops Lake area (Fig. 20D), the sub-Eocene unconformity delineates a broad depression at least 15 km wide, carved in Triassic and older bedrock. Eocene sedimentary and volcanic rocks were deposited in this depression, and modern streams have incised their valleys 100-200 m below its floor. The floor of the depression has a minimum elevation of 450 m on the south shore of Kamloops Lake and rises to about 750 m to the south (Fig. 20D). The depression extends along Thompson River valley from Kamloops to Ashcroft, where it is 480-650 m elevation and coincides with the floor of the Ashcroft strath (Tribe, 2003).

Across Okanagan Valley, near and north of Kelowna, Eocene base level was 350-500 m elevation, as defined by flanking Eocene strata at Mount Boucherie and Black Knight Mountain (Fig. 20E) and by Eocene strata near Enderby. At Kelowna (Fig. 20E), the sub-Eocene unconformity defines a broad, 30 km-wide valley in which sediments of the Eocene White Lake Formation (Es in Fig. 20E; site 23 in Table 2, Fig. 17) were deposited near 400 m elevation. The unconformity rises to over 1000 m elevation on both sides of the valley, and parallels the present-day highland and plateau surfaces (Figs. 20E, 22). The sub-Eocene unconformity thus has 700 m relief in this region. At Enderby, the sub-Eocene unconformity defines a broad depression with a
minimum elevation of about 450 m and relief of 700 m (site 28 in Table 2, Fig. 17; Journeay et al., 2000). South of Penticton, the sub-Eocene unconformity is a broadly planar, gently northward-dipping unconformity at 800-1000 m elevation overlain by Springbrook conglomerate (Es in Fig. 20F; site 31, Table 2, Fig. 16).

Paleocurrents and Provenance

Drainage reconstruction uses documented paleocurrent and clast provenance data from Cretaceous and Cenozoic fluvial sediments. Although paleocurrent determinations are few and are scattered over the large study area, they define a broadly northward regional drainage system. Clast provenance and paleocurrents in Late Cretaceous to Paleocene fluvial sediments indicate north- and northwest-directed transport in the southeastern Coast Mountains and northern Pavilion Range (Fig. 16; Schiarizza et al., 1997; Mahoney et al., 1999; Riesterer et al., 2001). Near Churn Creek, along Fraser River, conglomerates with provenance to the west and south indicate a north-flowing stream in Paleogene time (Fig. 16; Mathews and Rouse, 1984). Pebble imbrication south of Merritt indicates that Eocene streams flowed northward along Fig Lake Graben valley toward Merritt (Fig. 16, site 15; Thorkelson, 1989).

The exception to broadly northward paleoflow is the Allenby Formation in the Princeton area, which has southward paleocurrents and northern provenance indicating a south-flowing stream during middle Eocene time (Fig. 16, site 13; Read, 2000). Read (1988a) describes what he interprets to be a fan-delta deposit in northern Thompson Plateau between Kamloops and Ashcroft (Fig. 16, site 34). No paleocurrent or provenance data were provided, but the implied flow direction is westward (Read, 1988a). In Okanagan Valley near Trinity Hills, clasts in Eocene sediments have a provenance to the north, northeast and south (Fig. 17, site 28; Mathews, 1981).

Paleo-physiographic Domains

Eocene landscape and drainage directions (Fig. 23) are reconstructed from the geology and physiography of the study area, the location of the sub-Eocene unconformity, and the distribution, paleocurrents and provenance of Eocene sediments. The main physiographic domains depicted are mountains, highlands, plains, and fluvio-lacustrine waterways.
Mountains (Fig. 9, ‘peak” pattern) are characterized by high relief and steep slopes. They are drained by a dense network of relatively low-order streams with steep gradients. Mountains have lost all traces of older landscapes. Modern mountain physiography is seen in the Coast Mountains (Fig. 16, 121.75°W, 49.75°N) and Selkirk Mountains (Fig. 17, 117.5°W, 50.4°N).

Highlands are characterized by moderate relief and gentle to intermediate slopes. They are drained by sparse stream networks that have low gradients near their headwaters on the highland surface and steep gradients near their mouths. Three types of highland are distinguished in Figure 9: igneous highland (cross pattern), volcanic highland (v pattern), and highland developed in older bedrock (dome pattern). Igneous highland is terrain underlain by intrusive rocks of the same age as the interval depicted, in this case Eocene. During this time, the terrain was elevated into hills by intruding, cooling rock masses. Volcanic highlands are underlain by calc-alkaline volcanic flows and air-fall deposits of Eocene age. They consist of low hills and irregular terrain exhibiting radial drainage near volcanic centres and disrupted drainage on and near volcanic deposits. Modern highland physiography is exemplified by Okanagan Highland (Fig. 17, 119°W, 49.5°N) and Shuswap Highland (Fig. 17, centred at 119.25°W, 51.2°N).

Plateaus and plains (Fig. 23, white) are areas of low relief. They are distinguished from one another by their elevation with respect to local base level: plains tend to be near or coincident with local base level; plateaus are elevated above local base level. Drainage development is generally poor. Cariboo Plateau (Fig. 16, 121.5°W, 51.5°N) is an example of a late Cenozoic plain developed on flat-lying flood basalts of Miocene age. Thompson Plateau (Fig. 16, 120.5°W, 50°N) is an example of a plateau: a low-relief area elevated above the floors of canyons and incised valleys several hundreds of metres below the plateau surface.

Fluvio-lacustrine waterways (Fig. 23, black dots) are mapped wherever large basins and valleys retain stratigraphic evidence of former rivers and lakes. They represent valleys and basins that were loci of sediment transport or deposition. Fluvio-lacustrine terrain is mapped mostly on plains, although waterways may extend into highlands and mountain regions. This terrain type is shown with a site symbol that may superpose other domains. Drainage directions are inferred from published stratigraphic information, regional slopes, and other geomorphic information. Modern fluvio-lacustrine
waterways include upper Thompson River valley along 50.75°N (Fig. 16) and Okanagan Valley along 119.5°W (Fig. 17).

**Eocene Landscape Reconstruction**

The map of paleo-physiographic domains (Fig. 23) provides a graphic representation of the Eocene landscape. To take advantage of modern outcrop patterns, the time frame depicted is ca. 40 Ma, when strike-slip fault activity along the Fraser and Yalakom fault systems (Fig. 15, FF and YF) was on the wane or had ceased (Monger, 1989; Coleman and Parrish, 1991). Eocene physiography of southwestern British Columbia bears some resemblance to modern-day physiography: a northwest-trending lowland bounded by higher land to the west and east. Relief and base level were also similar to today.

Highlands and mountains existed in the region east of Kamloops during the Eocene. Shuswap and Quesnel highlands, and Cariboo and Selkirk mountains are underlain by Precambrian, Paleozoic and Mesozoic bedrock that experienced orogeny and metamorphism during Paleozoic and Mesozoic time (Monger et al., 1982; Brown and Journeay, 1987). The highlands and mountains of the Eocene are interpreted to date from that time.

Highlands also existed in the region of the modern southern Coast Mountains during the Eocene. Geology and structure indicate this region was a contractional orogen of east- and west-vergent thrust faults ca. 97-91 Ma (Monger and Journeay, 1994). The region is intruded by Jurassic and Cretaceous plutons, which require overlying bedrock in which to intrude. The combination of pervasive igneous intrusion and the development of a regional thrust belt would have formed highlands and possibly mountains during Late Cretaceous time. North-directed paleocurrents in Late Cretaceous to Paleocene fluvial sediments near Churn Creek (Fig. 16, black arrows; Schiarizza et al., 1997; Mahoney et al., 1999; Riesterer et al., 2001) also support the existence of highlands in the area of the southern Coast Mountains.

Highlands are reconstructed in the Okanagan region, where poorly dated Late Cretaceous to Paleogene intrusions are exposed at the surface. At several localities, Eocene volcanic and sedimentary rocks overlap these intrusions, establishing the age of the sub-volcanic surface as Paleocene to early Eocene.
Fluvio-lacustrine basins existed along Thompson River valley from Kamloops to Ashcroft, in Nicola Lake valley, along Okanagan Valley near Kelowna, and in the Horsefly-Quesnel area of Cariboo Plateau. High-resolution digital elevation models reveal an anabranching valley system fed by headwaters in the Quesnel and Shuswap Highlands and trending northwest to join Fraser River valley near Macalister. The valley system retains traces of Eocene fluvial and lacustrine deposits (sites 9, 10 on Fig. 16, Table 2) and is mapped as a fluvio-lacustrine waterway in Figure 9. A profile of the valley system near Horsefly is shown in Figure 20B.

Plains or lowlands eroded into older bedrock existed in the regions known today as Thompson, Cariboo and Chilcotin plateaus. Plains continue to the northwest, and were the corridor for regional northward drainage during early Cenozoic time. The physiography of southernmost Chilcotin Plateau and northwest Pavilion Range (Fig. 16, 122.25°W, 51.2°N) suggests that region is an exhumed plain of probable mid-Cretaceous to Eocene age. It corresponds to the surface on which Miocene flood basalts were erupted, but it also retains traces of Late Cretaceous, north-flowing river systems (Schiarizza et al., 1997; Mahoney et al., 1999; Riesterer et al., 2001), and scattered Eocene sedimentary and volcanic rocks.

**Discussion**

The prevalence of coal-bearing fluvial and lacustrine rocks in the Eocene sedimentary record distinguishes the Eocene as a time of ponded and disrupted drainage. No lacustrine or coal-bearing rocks are known from earlier deposits, and they are uncommon in the Miocene sedimentary record. Eocene sedimentary strata are located near modern base level, and throughout the study area appear inset into a higher, older peneplain, or extensive erosion surface, that dates back at least to the Late Mesozoic. Sometime between Late Mesozoic and Eocene time, rivers incised over 1000 m below the older erosion surface. By middle Eocene time, incision ceased, and fluvial and lacustrine deposition began in the valleys and lowlands.

The cause of base level change, regional fluvial incision and drainage disruption is unclear. Volcanism, thermal-induced uplift, orogeny or other tectonic events are possible causes. Alternatively, or in concert with the aforementioned causes, middle Eocene Fraser faulting may have opened a new, shorter route to the Pacific Ocean. This would have lowered base level and initiated headward stream erosion in a
northward direction along the trace of the Fraser Fault, which would have captured streams formerly flowing north.

Topographic highs near Big Bar and Quesnel (Fig. 16, dotted outline) are parallel to, and east of, the Fraser Fault. The high areas close to the north-northwest and broaden to the southeast (Fig. 16). Their configuration resembles north-plunging antiforms. The highs are sub-parallel to the theoretical orientation of folds in a simple shear model of convergent, dextral strike-slip faulting (Wilcox et al., 1973), and are interpreted to have formed from Cretaceous through Eocene time by activity on the nearby Fraser Fault. Near Churn and Big Bar creeks, the eruption of Miocene Chilcotin basaltic flows was influenced by these topographic highs (Mathews and Rouse, 1984), which proves that the regions were highland prior to Miocene volcanism. South of Macalister, isolated basins formed along the Fraser Fault and received thick sequences of coarse sediments. Near Big Bar Creek (site 5 in Table 2, Fig. 16), geologic relationships indicate the Eocene Fraser River valley was buried by 600 m of sediment between the Eocene and Miocene.

The anabranching fluvio-lacustrine waterway trending northwest from Shuswap and Quesnel highlands (Fig. 23) joins Fraser River valley near Macalister, a point where Fraser River valley changes from a mature broad valley in the north to a narrow rock-walled canyon in the south (Fig. 16). In the northern part of the study area near Quesnel, the elevation range of Oligocene, Miocene and Pliocene strata exceed one another in stratigraphic order (Fig. 19, northern transect), reflecting in-filling of a depression, namely the broad Fraser River valley north of Macalister. Paleocurrents and provenance of the Australian Creek Formation in the Fraser River valley near Quesnel indicate north-flowing streams in early Oligocene time (Fig. 16; Rouse and Mathews, 1979; Long and Graham, 1993). These relationships imply that Fraser River valley north of Macalister is early Cenozoic or possibly Mesozoic in age, in contrast to the south where the valley is Cenozoic in age.

Thompson River is another example of a modern stream with a two-stage developmental history. Upstream of Spences Bridge, modern Thompson River is underfit for its valley, which is interpreted to be Eocene or older. However, downstream of Spences Bridge, the shape of the sub-Eocene unconformity and the dimensions of the river valley change markedly. Lower Thompson River flows in a narrow, V-shaped valley carved entirely in Cretaceous Spences Bridge Group volcanic rocks ( Tribe, 2003).
An isolated coal occurrence of probable Eocene age is reported at 660 m elevation (site 17 on Figs. 16, Table 2; Duffell and McTaggart, 1952), which corresponds roughly to the elevation of the floor of the broad Eocene depression extending from Kamloops to Spences Bridge. The modern Thompson River valley downstream of Spences Bridge is thus younger than Eocene because Eocene base level was 400 m above modern river level.

Okanagan Valley is thought by some to be the trace of a north-trending, low-angle normal fault that brought Paleogene gneiss to the surface in Eocene time (Templeman-Kluit and Parkinson, 1986). Others note that the sub-Eocene surface is an unconformity rather than a fault and consider the gneiss to be Jurassic in age (Bardoux, 1985; Okulitch, 1987; Thompson and Daughtry, 1994). They consider Okanagan Valley near Vernon to be a half-graben or graben with extension of about 1 km. Geomorphic observations presented here support the latter interpretation, namely that Okanagan Valley is, in part, fluvial or subaerial in origin, and was not produced by major extensional detachment faulting.

The reconstructed Eocene landscape includes highlands at the site of the present-day southern Coast Mountains (Fig. 23), an interpretation that is consistent with isotopic and fission track dating studies in the region (Parrish, 1983; Reiners et al., 2002). Currie (L. Currie, unpublished data, 2002) examined fission tracks in apatites throughout southwestern British Columbia and obtained ages of 66-115 Ma east and west of Fraser Fault. Her data suggest a northwest-trending core of rapidly rising, cooling crust with young fission track ages of 8-18 Ma, surrounded by successively older terrain with fission track ages up to 100 Ma.

In contrast to studies that infer Eocene relief in the southern Coast Mountains, apatite (U-Th)/He ages in the central Coast Mountains at 54°N are interpreted as evidence that the present relief is young (ca. 4 Ma) (Farley et al., 2001). Farley et al. (2001) state their data could be interpreted as indicating a mountain range with the same relief and general topography over the past 10 Ma as today. However, the assumption of intense glacial incision leads them to their preferred hypothesis of young, 4 Ma-old relief in the central Coast Mountains.

The preservation of Eocene and older landform relicts in southern British Columbia implies only modest glacial erosion on a regional scale. It also implies longevity of the landscape that contradicts some models of tectonic evolution of the
southern Canadian Cordillera, for example the Okanagan extensional shear model (Templeman-Kluit and Parkinson, 1986) and the Baja-B.C. hypothesis, whereby dextral terrain displacement of several 1000 kilometres occurred along the west coast of North America during Cretaceous and Cenozoic time (Irving et al., 1985; Umhoefer, 1987).

**Conclusions**

Eocene landscape and drainage directions are reconstructed from the geology and physiography of the study area, the location of the sub-Eocene unconformity, and the distribution of Eocene sedimentary rocks. Eocene sedimentary rocks have the lowest position in the landscape, and are found in large valleys and topographic depressions. They are located near modern base level, and throughout the study area appear inset into a higher, older peneplain, or extensive erosion surface that dates back at least to the Mesozoic.

This study outlines the regional development of physiography in the period leading up to, and during, the Eocene. The southern Interior Plateau is an ancient landscape containing relict landforms of Mesozoic and Cenozoic age, surrounded by mountain ranges devoid of most traces of old physiography. Cretaceous to Paleocene sedimentary strata are elevated several hundred metres above Eocene sedimentary strata. Sometime during Late Cretaceous to middle Eocene time, regional base level dropped throughout the southern Interior Plateau. Rivers incised over 1000 m below the older erosion surface, producing significant topographic relief. Incision ceased by middle Eocene time, and fluvial and lacustrine deposition began in the valleys and lowlands.

A map of reconstructed paleo-physiography and drainage directions is presented for middle to late Eocene time (ca. 40 Ma). The reconstructed Eocene landscape resembles that of today: a northwest-trending swath of highlands, plateaus, plains and deeply incised valleys, bounded by higher land to the west and east. Base level elevation during Eocene time ranged from 400 to 1300 m. Eocene relief also ranged from 400 to 1300 m. Highlands, and possibly mountains, existed in the southern Coast Mountains. Fault-induced topography developed along the trace of the Fraser Fault. Highlands existed southwest of Kelowna and into the Selkirk Mountains. Low-relief plateaus and plains extended northwest throughout the region.

Regional drainage during the Eocene was broadly northward, in contrast to the modern southward drainage. Fluvio-lacustrine basins existed along Fraser River valley.
north of Macalister, North Thompson River valley, Thompson River valley from Kamloops to Ashcroft, Nicola Lake – Merritt valley, and Okanagan Lake valley near Kelowna. Drainage was northwest from Quesnel and Shuswap highlands to Fraser River valley north of Macalister.

Base level rose after middle Eocene time, causing Oligocene to Miocene strata to partially fill the Eocene valleys and basins. Modern southward drainage along Fraser, Thompson and Okanagan rivers was established after the Miocene. Preservation of landform remnants of Eocene age suggests that glacial erosion was highly variable in space, with only a modest effect at regional scales.

**Acknowledgments**

John Clague (SFU) and Bob Anderson reviewed the manuscript. Base Mapping and Geomatic Services, Province of British Columbia provided the digital elevation data. This work was supported by an NSERC PGS-B scholarship, NRCan Earth Sciences Sector supplement, SFU Graduate Fellowships and Clague's NSERC Operating Grant.
Figure 15. Map of study area showing towns, rivers, lakes and physiographic regions (block print) and sub-regions, and locations of cross-sections. Also shown are terrestrial deposits of Cretaceous (blue) and Eocene (orange) age, including subaerial volcanic flows, pyroclastic deposits, and fluvial and lacustrine sediments. Bedrock geology from Joumeay and Williams (1995) and Joumeay and Monger (1998).
Figure 16. Shaded relief map of the western part of the study area showing the locations of documented Eocene sedimentary rocks (circles, Table 2), paleoflow indicators (arrows), constructional volcanic forms (triangles, Table 3) and cross-sections. Dotted lines delineate topographic highs referred to in the text.
Figure 17. Shaded relief map of the eastern part of the study area showing the locations of documented Eocene sedimentary rocks (circles, Table 2), paleoflow indicators (arrows) and cross-sections.
Figure 18. Index map of transects shown in Figure 19. All sedimentary rocks (symbols) within the dotted lines are projected onto profiles shown in Figure 19.
Figure 19. Diagrams showing the elevation range of sedimentary strata of different age along four transects outlined in Figure 18. The elevation range of Eocene sedimentary strata is shaded grey. Vertical exaggeration 80x.
Figure 20. Geologic cross-sections showing the sub-Eocene and sub-Miocene unconformities. Vertical bars on sections A, B, C and E denote the amount of relief on the sub-Eocene unconformity. Geology from Bostock (1941), Ewing (1981), Bardoux (1985), Journey and Monger (1994) and Panteleyev et al. (1996). Depth to bedrock in Okanagan Valley from Eyles et al. (1991) and Vanderburgh and Roberts (1996). Ordinate scale starts at local base level. Vertical exaggeration 5x.
Figure 21. View looking east along Nicola Lake - Merritt valley. The flaring V-shaped valley is partially filled with Eocene to Quaternary age sediments. The valley was carved in the late Mesozoic to early Cenozoic Thompson Plateau, which comprises the elevated terrain on the right and left horizon, respectively.
Figure 22. View from Kelowna looking south along Okanagan Lake. Mount Boucherie, the rounded hill in centre of photograph, is an Eocene dacite dome flanked by fluvial and lacustrine strata of the Eocene White Lake Formation. The gently dipping surface between arrows approximates the location of the sub-Eocene unconformity on the west side of Okanagan Lake. Thompson Plateau and Okanagan Highlands comprise the elevated terrain on the horizon.
Middle to Late Eocene (ca. 40 Ma)
Post-Fraser Faulting

Figure 23. Reconstructed physiography and drainage directions during Eocene time about 40 million years ago.
<table>
<thead>
<tr>
<th>No.</th>
<th>Age, formation</th>
<th>Location</th>
<th>Brief description and paleoenvironment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mid-Eocene</td>
<td>Siwhe Creek</td>
<td>1000 m of fault-bounded sandstone, conglomerate and shale deposited in fluvial and piedmont fan settings.</td>
<td>Duffell and McTaggart, 1952</td>
</tr>
<tr>
<td>2</td>
<td>Eocene, Jones Creek beds</td>
<td>Carpenter Lake</td>
<td>Gently dipping conglomerate, shale, sandstone and lignite, fault-bounded on northeast.</td>
<td>Schiaririzza et al., 1997</td>
</tr>
<tr>
<td>3</td>
<td>Eocene, Hat Creek Fm.</td>
<td>Hat Creek</td>
<td>2000 m of fault-bounded sandstone, conglomerate and coal deposited in fluvial, marsh and lake settings.</td>
<td>Church, 1975; Read 2000</td>
</tr>
<tr>
<td>4</td>
<td>Eocene, Coldwater Fm.</td>
<td>Nicola Valley</td>
<td>230 m of basal conglomerate, breccia, sandstone, shale and coal.</td>
<td>Cockfield, 1961</td>
</tr>
<tr>
<td>5</td>
<td>Eocene</td>
<td>Churn Creek – Big Bar</td>
<td>Conglomerate, clay, bentonite and lignite of south or west provenance.</td>
<td>Mathews and Rouse, 1984</td>
</tr>
<tr>
<td>6</td>
<td>Mid-Eocene, Chu Chua Fm.</td>
<td>Chu Chua, Clearwater</td>
<td>800 m of conglomerate, sandstone, shale and coal deposited in fluvial and lacustrine settings.</td>
<td>Campbell and Tipper, 1971; Schiaririzza and Preto, 1987</td>
</tr>
<tr>
<td>7</td>
<td>Mid-Eocene, Tranquille Fm.</td>
<td>Kamloops Lake</td>
<td>500 m of lacustrine tuffaceous sandstone, siltstone, and conglomerate dipping up to 35°.</td>
<td>Graham and Long, 1979; Ewing, 1981</td>
</tr>
<tr>
<td>8</td>
<td>Eocene, McAbee Beds</td>
<td>McAbee-Savona</td>
<td>Mudflows and 130 m of lacustrine deposits.</td>
<td>Ewing, 1981</td>
</tr>
<tr>
<td>9</td>
<td>Mid-Eocene</td>
<td>Horsefly - Quesnel</td>
<td>Lacustrine claystone, siltstone, sandstone, tuff and conglomerate containing plant and freshwater fish fossils.</td>
<td>Panteleyev and Hancock 1988; Panteleyev et al., 1996</td>
</tr>
<tr>
<td>10</td>
<td>Mid-Eocene</td>
<td>Horsefly</td>
<td>Fossil freshwater fish in lacustrine sediments.</td>
<td>Wilson, 1977</td>
</tr>
<tr>
<td>12</td>
<td>Eocene, Allenby Fm.</td>
<td>Hope</td>
<td>Fault-bounded conglomerate and sandstone strata with subvertical dips.</td>
<td>Monger, 1969</td>
</tr>
<tr>
<td>No.</td>
<td>Age, formation</td>
<td>Location</td>
<td>Brief description and paleoenvironment</td>
<td>Reference</td>
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</tr>
<tr>
<td>13</td>
<td>Mid-Eocene, Princeton Group</td>
<td>Princeton</td>
<td>Sandstone, siltstone, coal and conglomerate with southerly paleocurrents and freshwater fish fossils.</td>
<td>Preto, 1979; Wilson, 1982; Read, 2000</td>
</tr>
<tr>
<td>14</td>
<td>Eocene, Princeton Group</td>
<td>Princeton</td>
<td>300 m of horizontal conglomerate, sandstone, shale and coal with steep dips in places.</td>
<td>Rice, 1947</td>
</tr>
<tr>
<td>16</td>
<td>Eocene, Allenby Fm.</td>
<td>Trapp Lake</td>
<td>No description available.</td>
<td>Journeay and Monger, 1994</td>
</tr>
<tr>
<td>17</td>
<td>Eocene ?</td>
<td>Spences Bridge</td>
<td>Sandstone, argillite and 2-m thick coal seam. Age control is poor.</td>
<td>Duffell and McTaggart, 1952</td>
</tr>
<tr>
<td>18</td>
<td>Eocene ?</td>
<td>Keatley Creek</td>
<td>Cobble conglomerate.</td>
<td>Duffell and McTaggart, 1952</td>
</tr>
<tr>
<td>19</td>
<td>Eocene ?</td>
<td>Botanie Creek</td>
<td>Small coal occurrences. Locations uncertain.</td>
<td>Duffell and McTaggart, 1952</td>
</tr>
<tr>
<td>20</td>
<td>Eocene ?</td>
<td>Ferguson Creek</td>
<td>Small occurrence. Location uncertain.</td>
<td>Duffell and McTaggart, 1952</td>
</tr>
<tr>
<td>21</td>
<td>Eocene ?</td>
<td>Cache Creek</td>
<td>Sandstone, shale and coal.</td>
<td>Duffell and McTaggart, 1952</td>
</tr>
<tr>
<td>22</td>
<td>Eocene ?</td>
<td>South Thompson River</td>
<td>No description available.</td>
<td>Okulitch, 1979</td>
</tr>
<tr>
<td>23</td>
<td>Eocene, White Lake Fm.</td>
<td>Kelowna</td>
<td>Mudstone, sandstone and conglomerate onlapping the Black Knight and Mt Boucherie dacite.</td>
<td>Bardoux, 1985</td>
</tr>
<tr>
<td>25</td>
<td>Eocene, White Lake Fm.</td>
<td>Summerland</td>
<td>Fluvial and lacustrine sediments overlying Eocene volcanic rocks in Summerland caldera.</td>
<td>Church et al., 1991</td>
</tr>
<tr>
<td>26</td>
<td>Eocene, White Lake Fm.</td>
<td>White Lake</td>
<td>Up to 1000 m of sandstone, conglomerate, coal and plant fossils interbedded with volcanic rocks.</td>
<td>Church, 1973</td>
</tr>
<tr>
<td>No.</td>
<td>Age, formation</td>
<td>Location</td>
<td>Brief description and paleoenvironment</td>
<td>Reference</td>
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</tr>
<tr>
<td>27</td>
<td>Eocene</td>
<td>Vernon, Lavington</td>
<td>Conglomerate associated with massive volcanic rocks, unconformably overlying older bedrock.</td>
<td>Thompson and Daughtry, 1994</td>
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<tr>
<td>28</td>
<td>Eocene outlier</td>
<td>Enderby Cliffs, Trinity Hills</td>
<td>Fluvial and lacustrine sandstone, siltstone, shale and conglomerate with east, northeast or southeast provenance.</td>
<td>Mathews, 1981</td>
</tr>
<tr>
<td>29</td>
<td>Eocene</td>
<td>Rock Creek</td>
<td>No description available.</td>
<td>Journeay et al., 2000b</td>
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<tr>
<td>30</td>
<td>Eocene ?</td>
<td>unnamed</td>
<td>Sedimentary strata not described.</td>
<td>Okulitch, 1979</td>
</tr>
<tr>
<td>31</td>
<td>Eocene Springbrook Fm.</td>
<td>Ollala, Brent Lake</td>
<td>Boulder conglomerate and talus unconformably overlying older bedrock.</td>
<td>Bostock, 1941; Church, 1973</td>
</tr>
<tr>
<td>33</td>
<td>Eocene ?</td>
<td>Harris Creek</td>
<td>Conglomerate, shale and sandstone.</td>
<td>Church and Suesser, 1983</td>
</tr>
<tr>
<td>34</td>
<td>Eocene</td>
<td>Deadman River</td>
<td>Conglomerate and sandstone of a possible fan-delta.</td>
<td>Read, 1988b, 2000</td>
</tr>
</tbody>
</table>
Table 3. Documented Eocene and older constructional volcanic landforms shown on Figure 16.

<table>
<thead>
<tr>
<th>No.</th>
<th>Age, formation</th>
<th>Location</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1</td>
<td>Triassic, Nicola Group</td>
<td>Near Princeton</td>
<td></td>
<td>Preto, 1979</td>
</tr>
<tr>
<td>V2</td>
<td>Cretaceous, Spences</td>
<td>Prospect Creek</td>
<td>Shield volcano</td>
<td>D. Thorkelson, pers.</td>
</tr>
<tr>
<td></td>
<td>Bridge Group</td>
<td></td>
<td></td>
<td>comm., 2001</td>
</tr>
<tr>
<td>V3</td>
<td>Cretaceous, Spences</td>
<td>Nicoamen River</td>
<td>Shield volcano</td>
<td>D. Thorkelson, pers.</td>
</tr>
<tr>
<td></td>
<td>Bridge Group</td>
<td></td>
<td></td>
<td>comm., 2001</td>
</tr>
<tr>
<td>V4</td>
<td>Cretaceous, Spences</td>
<td>Shovelnose Mountain</td>
<td>Flow-banded rhyolite</td>
<td>Cockfield, 1961</td>
</tr>
<tr>
<td></td>
<td>Bridge Group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V5</td>
<td>Eocene, Kamloops Group</td>
<td>Cache Creek</td>
<td>Rhyolite dome</td>
<td>Church, 1975; Read 2000</td>
</tr>
<tr>
<td>V6</td>
<td>Eocene, Kamloops Group</td>
<td>North of Tranquille</td>
<td>Kissick and Doherty cones, tuff rings</td>
<td>Ewing, 1981</td>
</tr>
</tbody>
</table>


CHAPTER FIVE
CRETACEOUS AND CENOZOIC PALEODRAINAGE IN THE
SOUTHERN INTERIOR PLATEAU, BRITISH COLUMBIA

Abstract

Physiographic mapping of high-resolution, DEM-based, shaded relief maps has delineated relict landforms and drainage networks in the southern Interior Plateau of British Columbia. Geomorphology, valley-fill geology and cross-cutting relationships with dated geologic structures indicate that a suite of early Tertiary and older valleys is preserved in the modern landscape. The correlation of physiography with sedimentary paleoenvironment suggests that some landform elements are exhumed features of middle Cretaceous age (ca. 100 Ma).

Landscape reconstructions provide evidence for long-lived, north-flowing drainage during Cretaceous and Eocene time, fed from headwaters in the Coast Mountains and Thompson and Okanagan Highlands. Cretaceous base level was more than 1000 m above modern sea level and is preserved in elevated tracts throughout the study area. The Eocene drainage network was incised into this surface. Base level during the Eocene was a minimum of 400 m elevation and declined gently northward. Volcanism and faulting in Eocene time disrupted drainage in places and caused ponding. During Oligocene and Miocene time, base level was some 500 m higher than during the Eocene, and Eocene valleys were partially buried. Miocene rivers in the Coast Mountains flowed eastward across Thompson Plateau and northward along Clearwater and Quesnel river valleys. Not until the Pliocene did the modern south-flowing Fraser, Thompson, Chilcotin and Okanagan drainages develop. Preservation of relict and exhumed landforms of Eocene and even Cretaceous age suggests that Quaternary glacial erosion was not extensive on a regional scale.

Introduction

This study attempts to look back to past landscapes. Geomorphic evidence of relict landforms and former base levels in southern and central British Columbia (Figure
24) is examined using physiography and drainage patterns interpreted from high-resolution shaded relief maps. The age of suspected relict landforms is estimated using published data on bedrock geology and structure. Cross-cutting geological relationships indicate that a suite of Tertiary and older valleys and other landforms is preserved in the modern landscape of British Columbia’s Interior Plateau. The correspondence between sedimentary paleoenvironment and physiography suggests that some landform elements are exhumed features of Late Cretaceous age (ca. 100 Ma). Reconstructed landscapes and drainage paths are presented for several times from the Late Cretaceous to the present.

Previous Work

Physiographic and paleodrainage studies in British Columbia reached the height of their popularity more than 50 years ago, when the only tools available for this type of research were field observations, topographic maps and some aerial photographs. Since then, work on drainage evolution has waned, despite widespread aerial photograph coverage, computer-aided mapping techniques and digital data sets. Modern work on paleodrainage is confined mostly to short sections in regional bedrock or surficial geology reports. The work of W.H. Mathews (1986, 1988, 1989, 1991; Mathews and Rouse, 1984) on the Cenozoic geology of southern British Columbia, however, is a notable exception.

Dawson (1895) was the first to suggest that Miocene Fraser River flowed northward down the regional slope of the Interior Plateau. Schofield (1921) remarked on the ‘big bend’ of Fraser River near Prince George, and a similar bend in Columbia River valley near Mica Creek. Both rivers flow northwest along the Rocky Mountain Trench, then turn almost 180° counter clockwise to continue along a straight southward course. Schofield (1921) suggested that, in Eocene time, the Fraser – Peace drainage divide was located south of Williams Lake near the modern confluence of Chilcotin and Fraser rivers. North of this divide, ancestral Fraser River and its tributaries flowed towards the modern Peace River and presumably eastward across the Rocky Mountains. Some time after the Eocene, a southerly flowing stream eroded headward and captured the north-flowing ancestral river, creating the modern south-flowing Fraser River.

Uglow (1923) mapped Eocene fluvial, lacustrine and coal-bearing strata near modern river level along North Thompson River valley 30 km south of Clearwater. The
strata demonstrate the existence of a river valley entrenched 1000 m below the surface of Thompson Plateau during or before the Eocene. Uglow (1923) concluded that peneplanation of the plateau surface occurred in Cretaceous time and that 1000 m of uplift is pre-Eocene in age.

Lay (1941) investigated the geology and paleodrainage along Fraser River. He postulated an ancestral Fraser River that flowed northeasterly through the Rocky Mountains in the Late Cretaceous. This interpretation is supported by the presence of lower Albian fluvial strata, which contain westerly derived metamorphic mineral grains, indicating eastward river flow during Early Cretaceous time (reported in Mathews, 1991). Lay (1941) postulated a pre-Miocene, and possibly Late Cretaceous, northward-flowing ancestral Fraser River near Quesnel based on the presence of imbricated, iron-stained quartzite conglomerate. He further suggested that southward flow was established in the Eocene or later.

Rice (1947) concluded that the modern drainage in the Princeton area of the southern Interior Plateau developed in Late Pliocene or early Pleistocene time and that drainage rearrangement in this area was the result of glaciation. Trettin (1961) mapped an elevated floodplain near Pavilion that he thought was a former valley of the Miocene Fraser River. Campbell and Tipper (1971) suggested the North Thompson – Clearwater River valley and other major drainage systems in southwestern British Columbia were established before Eocene time. Fulton (1975) suggested the valleys of Nicola River and Thompson River are antecedent and date back to early Tertiary or possibly Cretaceous time. He interpreted Nicola Lake valley as a Tertiary feature that was exhumed during the Late Tertiary and Quaternary.

Bevier (1983) concluded that Fraser and Chilcotin rivers established their modern courses in Late Miocene time, whereas Mathews (1989) suggested modern Fraser River was established as recently as the Late Pleistocene. Mathews and Rouse (1984) identified northward paleoflow indicators in Miocene quartzite-rich gravels near Gang Ranch and Big Bar Creek, and postulated a Miocene river that flowed northward along Fraser River valley north of the Chilcotin River junction. Mathews and Rouse (1984) mapped Pliocene lava flows that advanced southward along a southward-narrowing valley near Gang Ranch and blocked local drainage. They postulated that Pliocene drainage was toward the north and that Fraser River acquired a southerly flow direction sometime after the Pliocene.
Read (1988a) mapped a Miocene drainage network near Bonaparte and Deadman rivers on northern Thompson Plateau that drained north and west. Mathews (1988) mapped Miocene stream channel segments in Okanagan Highlands that appear to be graded to a common base level. Higher-order stream segments of Miocene age have been documented in Okanagan Highlands, but the flow direction of the stream is unknown (Mathews, 1991). Mathews (1991) mapped a northerly flowing ancestral stream in the vicinity of Horsefly and scattered, low-order stream segments in the Cariboo region. He postulated the current model of physiographic evolution of British Columbia, which calls for Late Cretaceous to early Eocene erosion and pediplanation over much of the province and three episodes of regional uplift from middle Eocene to Pliocene time, separated by periods of sustained subaerial erosion (Mathews, 1991).

Recently, Struik et al. (1997) examined a new digital elevation model of British Columbia and identified an ancient watershed in Fraser Basin that drained highlands to the north, west and south, converging at Prince George. From Prince George, the trunk river flowed to the east, perhaps through the Rocky Mountains, but later was diverted to the south by uplift of the Rocky Mountains. Tribe (2002, 2003) examined landforms on DEM-based shaded relief maps and postulated preserved remnants of early Tertiary drainage patterns in southwestern British Columbia. She described an eastward-flowing paleodrainage network in the southern Coast Mountains that predates Eocene strike-slip faulting along Fraser Fault (Tribe, 2002).

Data Sources

Shaded relief maps, slope maps and topographic profiles used in this study were derived from 1:250 000-scale, 25-m gridded DEMs using ArcView and ArcINFO software on a personal computer. Aerial photo interpretation of Fraser, Thompson and North Thompson River valleys was done with 1:50 000-scale, black-and-white aerial photographs. Stream and other geographic names are from 1:50 000- and 1:250 000-scale topographic maps. Geological information is from regional-scale maps and detailed reports cited in the references, and from digital geology compilations (Journeay and Monger, 1998; Journeay and Williams, 1995).
**Study Area Physiography and Drainage**

The study area consists of the southern Interior Plateau physiographic province of British Columbia, extending from 49°N to 53°N and from 118°W to 123°W (Fig. 24). This physiographic province consists of northwest-trending contiguous plateaus and highlands (Mathews, 1986), and includes Fraser River from Quesnel to Vancouver and the Okanagan region. The study area covers more than twelve 1:250 000-scale NTS topographic maps.

Physiography is shown with great detail and accuracy on DEM-based shaded relief maps (Figs. 25, 26). The Interior Plateau is clearly visible as the low-relief, relatively undissected terrain nestled between rugged mountain ranges. Chilcotin, Cariboo and Thompson plateaus are characterized by low to moderate relief and average elevations ranging from 900 m in the north to 1500 m in the south. They are bounded to the west by the deeply incised Coast Mountains, Cascade Mountains and Pavilion Ranges. Okanagan, Shuswap and Quesnel Highlands are characterized by moderate relief and have average highland elevations of 1500-1800 m. They are bounded to the east by Cariboo, Monashee and Selkirk mountains.

Drainage is broadly south and southwest along Fraser, Thompson, Okanagan and Kettle rivers and their tributaries (Fig. 24). Exceptions to southward drainage are Shuswap River, which drains to the northwest through a series of lakes to South Thompson River, and Chilcotin and Similkameen rivers, which flow to the southeast.

**Bedrock Geology**

Landscapes in the study area are developed on Paleozoic and Mesozoic rocks, which are briefly described below. Most of the rocks have been metamorphosed and penetratively deformed, and are overlapped by undeformed Late Mesozoic and Cenozoic strata. Landforms throughout the study area bear no relation to the geologic history and setting implied by bedrock older than about 100 Ma.

Bedrock in the southern Interior Plateau consists mainly of Paleozoic and Mesozoic volcanic, sedimentary and metamorphic rocks intruded by plutonic rocks of Mesozoic age (Campbell and Tipper, 1971; Monger, 1989; Gabrielse and Yorath, 1991). The eastern study area experienced compressional and extensional deformation during Paleozoic and Mesozoic time along north-trending faults, such as Okanagan, Eagle
River and Louis Creek faults (Monger and Price, 1979; Monger et al, 1982; Brown and Journeay, 1987).

Bedrock in the southern Coast Mountains is dominated by Jurassic to Late Cretaceous intrusions of the Coast Plutonic Complex with minor septa of older greenschist- and higher-grade sedimentary and volcanic rocks. In Late Cretaceous time, the Coast Mountains and western Pavilion Ranges experienced regional compressive deformation along northwest-striking thrust faults, including the Harrison Lake, Owl Creek, Bralorne and Kwioek Creek faults, (Journeay and Monger, 1994; Schiarizza et al., 1997). The southern part of study area last experienced marine conditions in the Cretaceous when the partly marine Taylor Creek Group was deposited in Tyaughton Basin (Garver, 1992; Schiarizza et al., 1997).

The study area was the site of restricted terrestrial deposition and widespread subaerial volcanism from Cretaceous through Eocene time (Mathews, 1991). The Cretaceous rock record consists of a northwest-trending swath of Spences Bridge Group volcanic rocks, with scattered Late Cretaceous fluvial conglomerate and sandstone in the western part of the study area (Schiarizza et al., 1997; Mahoney et al., 1999). Restricted Eocene fluvial and lacustrine sedimentary strata are overlain by widespread volcanic flows and breccias of the Eocene Kamloops Group and correlative rocks.

In the southwest part of the study area, early Tertiary and older rocks and structures are offset by strike-slip faults. The northwest-trending Yalakom and Hozameen faults were active in Late Cretaceous to early Tertiary time, with 80-125 km of dextral offset (Schiarizza et al., 1997). Most fault movement is thought to have occurred from 55 to 47 Ma, although the fault system may have been active since Late Cretaceous, and some parts of the fault were active into the late Eocene (Schiarizza et al., 1997). Estimates of offset differ depending on the piercing points chosen. Schiarizza et al. (1997) prefer about 115 km of displacement. North-trending Fraser Fault, of middle Eocene age, cross-cuts the northwest-trending Yalakom and Hozameen fault systems. Piercing points indicate 70-120 km of dextral strike-slip movement from 47 to 35 Ma (Monger, 1989; Coleman and Parrish, 1991; Schiarizza et al., 1997). Normal and strike-slip faults with smaller displacements on Thompson Plateau and Okanagan Highland, some with northeast or eastward strikes, are red to development of grabens and half-grabens during early Cenozoic time (Monger, 1985).
Oligocene and Miocene fluvial and lacustrine strata occur in the upper Bonaparte River area (Read, 2000) and at scattered sites on Okanagan Plateau beneath basalt flows (Mathews, 1988). The Miocene was a time of widespread basaltic volcanism. Extensive flat-lying Chilcotin basalts, most dated at 9-15 Ma (Mathews, 1989), occur throughout northern Thompson, Cariboo and Chilcotin plateaus. Miocene-age basalts also crop out on Okanagan Plateau between Kelowna and Vernon (Mathews, 1988). Pliocene basalt flows are confined to valleys near Merritt and Clearwater (Hickson, 1986). Southwestern British Columbia experienced regional uplift, on the order of 1-2 km, during Late Miocene-Pliocene time (Parrish, 1983). Minor volcanism occurred during Quaternary time. British Columbia was repeatedly glaciated during the Pleistocene (Clague, 1989).

**Geomorphic Evidence of Relict Landforms**

Anomalous geomorphology and drainage patterns in the study area indicate that modern streams are not adjusted to the landscape, and that some elements of the landscape are relicts from earlier times (Tribe, 2002, 2003). The variety of drainage patterns and the range in size and direction of valleys illustrate that not all regions experienced the same developmental history (compare, for example, the drainage pattern at 51°N, 121°W with that at 50°N, 122°W; Fig. 25). Cross-cutting valleys are evidence of at least two generations of valley formation. For example in northern Thompson Plateau, southwest-trending dendritic valleys are cross-cut by the south- and southeast-trending valleys of Bonaparte and Deadman rivers (Fig. 25, near circle 20 and 34). Many valleys are drained by two underfit streams flowing in opposite directions from a low divide on the valley floor. Such valley-floor drainage divides are widespread and numerous in Thompson Plateau and the Coast Mountains (Tribe, 2002, 2003).

Elongate, natural lakes in rock-walled valleys further indicate that modern drainage patterns are not adjusted to the landscape. Examples include Okanagan and Quesnel lakes. Some elongate lakes, such as Seton, Kamloops and Shuswap lakes, are oblique to mapped geologic boundaries and structures. Other broad valleys that do not contain lakes are also oblique or perpendicular to mapped geologic boundaries. These valleys were not initiated by faulting or weak lithologies, but rather were carved by rivers.
Physiography and the Rock Record

Anomalous geomorphology and drainage patterns are strong evidence that the landscape has a long history. The age of the landscape can be constrained using cross-cutting relationships with dated rocks and structures.

Unconformities and Intrusions

The distribution of preserved terrestrial rocks of Cretaceous and Tertiary age, including lacustrine, fluvial and subaerial sedimentary rocks, volcanic flows and pyroclastic deposits, is shown in Figure 27. Figure 27 also shows the distribution of Tertiary and poorly dated Cretaceous-Tertiary intrusions, and unconformities. Intrusive rocks provide a maximum age for an unconformity. A minimum age is given by the age of the oldest rocks deposited on the unconformity.

A sub-Cretaceous unconformity is preserved in Thompson, Cariboo and Chilcotin plateaus, the neighbouring Cascade and Pavilion ranges, and northeastern Coast Mountains. It is not present throughout Okanagan Highland or along the eastern margin of Interior Plateau. A sub-Eocene unconformity is preserved throughout Interior Plateau, including Okanagan Highland, but is missing in the mountain ranges to the east and the Coast Mountains to the west. Sub-Miocene and younger unconformities are well preserved throughout the study area, including a few places in the Coast Mountains and Cascade Ranges. Columbia Mountains have no terrestrial rocks younger than Paleozoic and exhibit only the modern unconformity. To summarize, the Interior Plateau has a long record of terrestrial deposition and retains parts of the sub-Cretaceous, sub-Eocene and younger unconformities. In contrast, adjacent mountain regions have lost most cover rocks, if indeed they were ever deposited there.

Sedimentary Rock Record

The distribution of terrestrial sedimentary cover rocks of mid-Cretaceous and younger age is shown in Figures 25 and 27. Most outcrops are too small to show on the maps and thus are indicated by symbols. Tables 4, 5 and 6 provide descriptions of each locality from published reports. Documented volcanic centres and constructional landforms, such as domes, shields and cones, are summarized in Table 7.

The oldest, continental deposits are Albian – Cenomanian (Late Cretaceous, ca. 100 Ma) to Paleocene fluvial sediments (Table 4, Fig. 25 squares). These strata occur
at scattered locations in the western part of the study area fringing the Coast Mountains, and in the northern part of the study area fringing Quesnel Highland (Fig. 25). The strata consist of chert-pebble and polymictic conglomerate and lesser sandstone, most lying with profound unconformity on older deformed sedimentary, intrusive or volcanic rocks. Most strata were deposited in high-energy environments such as braided river channels, alluvial fans, and high-gradient streams proximal to active volcanoes. Minor siltstone (e.g., in Churn Creek Group, square 6, Fig. 25, Table 4) records lacustrine deposition and implies drainage disruption. Some fluvial strata are folding and faulted (Mahoney et al., 1992).

Clast provenance and paleocurrents in Churn Creek Group conglomerate and correlative strata in Pavilion Ranges and western Interior Plateau indicate west- to northeast-directed transport during Albian and Cenomanian time (Fig. 25; Schiarizza et al., 1997; Mahoney et al., 1999; Riesterer et al., 2001). Streams flowed northward from high ground comprising upthrust sheets of Methow terrane (Mahoney et al, 1992; Riesterer et al., 2001). Conglomerates with provenance to the west and south near Churn Creek along Fraser River also indicate a north-flowing stream in early Tertiary time (Mathews and Rouse, 1984).

Reported paleocurrent indicators are assumed to be corrected for structural dips, although structural correction is not explicitly stated in the reports. Block rotation is known to have occurred in the Churn Creek area. The amount of block rotation must be removed from the paleoflow direction to get the corrected flow direction. In general, structural dips do not significantly affect estimates of paleoflow directions because other data, such as clast provenance and thrust faulting of nearby terrain, were used to infer paleo-flow directions.

Middle Cretaceous to Paleocene strata do not occur in present-day valleys or basins; rather they underlie adjacent, elevated planated geomorphic surfaces. For example, the Silverquick Conglomerate occurs near, or in, terrain that was a long-lived highland (Squares 7, 9, Fig. 25, Table 4). It is associated with low-relief, elevated land in the Botanie Creek area and indicates topographic inversion, in which a Cretaceous riverbed now stands as an upland. Silverquick Conglomerate commonly is found in areas of younger Cenozoic fluvial sediments, for example near Hat Creek and at Churn Creek.
The Eocene sedimentary record is one of areally restricted sedimentation in rivers, lakes and swamps (Table 5). Eocene sediments occur almost exclusively in large valleys and basins. The association of Eocene fluvial and lacustrine deposits with poorly drained, anomalously large valleys is evidence of the antiquity of the valleys. Paleocurrent data indicate predominantly northward river flow throughout the study area, except near Princeton where strata record southerly paleocurrents (circle 13, Fig. 25, Table 5; Read, 2000) and in the Okanagan area near Trinity Hills where provenance is to the north, northeast and south (circle 28, Fig. 26, Table 5; Mathews, 1981). Eocene landscape and drainage are discussed in detail in Chapter 4.

The Oligocene sedimentary record is restricted to outcrops of the Australian Creek Formation. Fluvial and lacustrine sediments of the Australian Creek Formation were deposited within Fraser River valley and adjacent Narcosli Creek valley near Quesnel (star 1, Fig. 25, Table 6; Rouse and Mathews, 1979). The sediments are limited in extent and, in most places, are covered by Miocene basalt flows. They were deposited in a broad valley that contained a north-flowing braided or anastomosing river. The valley became filled with fan sediments deposited by tributary streams (Rouse and Mathews, 1979; Long and Graham, 1993).

Miocene sediments occur mainly beneath Miocene-Pliocene Chilcotin basalt on Thompson and Cariboo plateaus and Okanagan Highland. They consist of fluvial sandstone and conglomerate. Some Miocene strata near Horsefly and in Okanagan Highlands contain gold-bearing gravel and were deposited in incised meandering channels (stars 7, 8, Fig. 26, Table 6; Mathews, 1988, 1991). The Miocene sedimentary sequence near Quesnel is capped by the Crownite Formation, which consists of diatomite deposited within the confines of the broad Miocene Fraser valley.

Several researchers report north-directed paleocurrents in Miocene sediments (Green, 1990; Read, 2000). East- and northeast-flowing streams have been inferred from imbricated pebbles in Miocene gravel near Quesnel (Levson and Giles, 1993). West-, northwest- and north-flowing Miocene streams have been reported in the Horsefly area (Panteleyev et al., 1996). Some south-directed current indicators have been reported from the middle Miocene Fraser Bend Formation near Quesnel (star 2, Fig. 25, Table 6; Rouse and Mathews, 1979).
Pliocene strata are rare in the study area. The only reported example is fluvial sediments beneath Pliocene basalt flows in the Fraser River valley near Leon Creek (star 10, Fig. 25, Table 6; Mathews and Rouse, 1984).

**Regional Base Levels**

Elevations of Cretaceous and Cenozoic sediments and volcanic centres listed in Tables 4-7 were projected onto cross-sections to elucidate base level trends in time and space. Three transects extend southeastward across the north, central and southern parts of the study area, and a fourth cross-section extends southward along Fraser River (Fig. 30). The cross-sections show general elevation trends for strata of different ages (Figs. 31-34).

Cretaceous to Paleocene strata are elevated several hundred metres above Eocene strata along all transects except the northern transect, where pre-Eocene and Eocene sedimentary strata are at similar levels. Horizontal Cretaceous fluvial strata occur at 1300-1600 m elevation near Pavilion (Fig. 29B; Bovis, 1985), at the same elevation as the Late Cretaceous Silverquick Formation in Hat Creek valley (Fig. 29C). The central transect shows that Cretaceous to Paleocene strata increase in elevation to the northwest into southern Chilcotin Plateau (Fig. 32).

Most Eocene strata range in elevation from 400 to 1200 m (Figs. 31-34). Eocene relief ranges from 400 to 1300 m. Relief on the sub-Eocene unconformity is at least 500 m in Fraser Valley near Macalister (Fig. 29A) and 700 m near Kelowna (Fig. 29E). Eocene base level is 800-1000 m elevation in southern Thompson Plateau and Okanagan Highland near Keremeos, where the sub-Eocene unconformity is overlain by Springbrook Conglomerate.

The elevation ranges of Oligocene, Miocene and Pliocene strata exceed one another in stratigraphic order, reflect progressive infilling of depressions and valleys. This relationship is clearly shown along the northern and Fraser River transects near Quesnel (Figs. 31, 34). The central and southern transects show that Miocene and younger sediments are at and above the Eocene level (Figs. 32, 33).

Eocene Okanagan Valley was buried to an elevation of 900 m by approximately 550 m of sediments prior to the Miocene. Post-Miocene incision ranges from 600 to 750 m (Figs. 29D, F). The King Edward Creek basalt flow of Miocene age (14.8 Ma; Mathews, 1988) crops out from 1550 to 910 m, draping the hillside at the northwest
corner of Okanagan Highland (Figs. 29D, F; Mathews, 1988). Demonstrable vertical relief of the sub-Miocene unconformity at this locality is 650 m. Post-Miocene exhumation of Okanagan Valley preceded deposition of the 0.8 Ma Lambly Creek volcanic flow (triangle 23, Fig. 26, Table 7; Mathews, 1988), which extends down a hillside to the modern valley floor.

Post-Pliocene incision near Kettle River is up to 645 m (Fig. 29D). The rugged topography of southeastern Okanagan Highland adjacent to the Selkirk Mountains has developed on early Cenozoic intrusive rocks (Journeay et al., 2000b), with at least 1400 m of vertical erosion (Fig. 29D). Some of this erosion, however, may be tectonic in origin and not indicative of erosion throughout the study area.

Cretaceous-Paleocene base level is elevated in the northwest along the central transect (Fig. 32), and Miocene base level is elevated in the northwest along the southern transect (Fig. 33). Both trends reflect Late Cenozoic uplift of the Coast Mountains relative to adjacent Thompson Plateau. To summarize, Late Cretaceous to Paleocene base level is elevated with respect to younger base levels. Eocene strata were deposited within valleys and basins on the Late Cretaceous to Paleocene surface. Oligocene to Miocene strata were deposited within Eocene valleys and basins. Valleys and basins were exhumed during Pliocene and Quaternary time.

Regional Erosion Surfaces

A general picture of terrain heights throughout the study area is provided by the map of regionally developed surfaces (Fig. 28). The map shows the extent of prominent erosion surfaces and their bounding elevations, as well as differences in the elevation of low relief terrain in the Interior Plateau. The map was constructed by examining DEMs that were colour-coded by elevation. The colour classes in Figure 28 were determined empirically. The categories represent the most common elevation ranges of planated surfaces. Some categories have overlapping ranges.

Mountains (gray in Fig. 28) have high relief, steep slopes and rugged profiles, with no planation surfaces. Highlands are less strongly dissected terrain above 1500 m elevation (yellow, Fig. 28). They are present throughout the southern Interior Plateau and fringe the surrounding mountain ranges. In general, highlands increase in elevation, and become better developed, toward the south.
The green surface (1100-1500 m) is found throughout the southern Interior Plateau from the International Boundary to Prince George. Isolated hills and mountaintops rise above this surface west of Fraser River in Chilcotin Plateau. This surface is interpreted to be Cretaceous in age in Thompson Plateau, where there are volcanic centres of Cretaceous age (triangles 2-4, Fig. 28, Table 7), and near Pavilion where horizontal Cretaceous sedimentary strata underlie a plateau surface (square 4, Fig. 28, Table 4; Bovis, 1985). Farther north, the surface corresponds to top of the Miocene Chilcotin Group flood basalts. It is also developed along Yalakom and Bridge River valleys in the Coast Mountains. The surface appears to be older in the western part of the study area than in the eastern and northern parts.

Two lower surfaces (blue and purple levels, 900-1140 m, Fig. 28) are restricted to Cariboo Plateau and are not as widespread as other surfaces. The blue surface defines the top of Miocene Chilcotin basalts. The purple surface comprises two valley systems that extend westward across Cariboo Plateau from Quesnel and Shuswap Highlands and northward along Fraser River valley. The northern valley system extends from Quesnel Lake near Horsefly towards Quesnel. The southern valley system extends from Mahood and Canim lakes towards Williams Lake. Tertiary fluvial and lacustrine strata, including Eocene and Miocene placer gold deposits, are located within the northern valley system, as are scattered outcrops of Cretaceous fluvial conglomerate (square 10, Fig. 28, Table 4). The southern valley system contains no mapped sediments older than Quaternary. Branching patterns and the distribution of high ground indicate that paleoflow was towards the northwest and north. The northern valley system is interpreted to have conveyed north-flowing streams during a prolonged period, from Eocene to Quaternary time, whereas the southern valley system is interpreted to have carried streams and glacial meltwater during Quaternary time.

The two pink surfaces in Figure 28 (400-1000 m) define a widespread erosion surface that coincides with the area of thick Quaternary deposits. In the Quesnel-Prince George region and Rocky Mountain Trench, the higher pink level (700-1000 m, Fig. 28) is associated with extensive drumlin fields and the lower pink level (400-600 m, Fig. 28) corresponds to a glaciolacustrine plain. In Thompson Plateau, Okanagan Highland and the Clearwater River area, the pink levels coincide with the sub-Eocene unconformity. The lower pink level in Okanagan Highland is underlain by Eocene White
Lake sediments and Eocene volcanic plugs (Mount Boucherie and Black Knight Mountain near Kelowna; circle 23, Fig. 28, Table 5).

Discussion

Anomalous geomorphology and drainage patterns throughout the study area suggest that modern drainage is not adjusted to the present landscape, and that some landforms and large valleys are relicts, dating back far into the geologic past. The relationship between sedimentary paleoenvironment and present-day geomorphology also indicates that some modern-day valleys date back to the geologic past. Relict landforms have been modified by surface weathering and erosion, but general valley trend and form are inherited features.

Cretaceous to Paleocene fluvial strata are associated with elevated planated surfaces of limited extent near Botanie Creek, Hat Creek, Pavilion and Deadman River (squares 4, 9, Fig. 25, Table 4). The locations of these strata indicate that remnants of a Late Cretaceous plain remain in southern British Columbia. This interpretation is supported by the elevation range of outcrops. Figures 32-34 show that Cretaceous strata are elevated with respect to younger sedimentary rocks.

An example of an exhumed, planated surface of Late Cretaceous age is found in the region north of Gold Bridge and west of Big Bar Creek, where Cretaceous Silverquick fluvial strata record north- and west-flowing streams (squares 7, 8; Fig. 25, Table 4). This region is characterized by a planar surface with a dense, pinnate drainage network that is not deeply incised compared to drainage in the Coast Mountains to the south. The planar surface corresponds to the surface on which Chilcotin Plateau basalts of middle Miocene age (Mathews, 1989) were deposited. It is the product of subaerial erosion and planation adjacent to the Coast Mountains dating back to Late Mesozoic time. The pinnate drainage network was not greatly modified by glacial erosion because it has V-shaped valleys and a dense, branching pattern. It is probably Pliocene or Quaternary in age.

Eocene sedimentary strata are fluvial and lacustrine in origin and occur within large valleys. They indicate that many large valleys were eroded to near present-day dimensions by or before middle Eocene time.

Some large valleys containing Eocene strata may have once been contiguous prior to Late Cretaceous to Eocene displacement along Yalakom and Fraser faults. If
fault displacements along the Yalakom-Hozameen fault system are restored, the eastern extension of Bridge River valley aligns with the Nicola-Merritt valley, and the western extension of Thompson River valley between Kamloops and Cache Creek aligns with Cretaceous and Eocene volcanic and sedimentary rocks in the Churn Creek - Gang Ranch area. These two correlations are speculative and demand further investigation.

No evidence was found to support crustal displacements of the magnitude required by paleomagnetic studies. Several paleomagnetic studies throughout western North America require 1000 km or more of displacement between 72 Ma and 50 Ma along as-yet-unmapped faults that may be located somewhere between Kamloops and Lillooet (Irving et al., 1985; Umhoefer, 1987; Johnston et al., 1996). If these hypotheses were correct, one might expect to see landforms resulting from such great displacements. For example, fault-induced relief or offset river valleys would provide evidence for such ground movements. However, no such signs of large-magnitude displacements have been identified in Thompson or Cariboo plateaus. Landscape reconstructions presented in Chapter 5 do not require or suggest fault displacements of more than about 200 km.

Most middle and late Cenozoic sediments crop out on plateau tops and in large valleys. They record fluvial and lacustrine environments. Near Quesnel, Miocene sediments record disrupted drainage and local ponding (stars 1, 2, 4, 9, Fig. 25, Table 6); in northern Thompson Plateau, they delineate low-order stream courses (stars 3, 6, Fig. 25, Table 6).

To summarize, base level was relatively constant in the Interior Plateau during Late Cretaceous time. During the Eocene, base level fell 500-700 m on average, resulting in incision of valleys. In the middle Eocene, valleys began to fill with sediment. Valley infilling persisted through the Oligocene and Miocene, raising base levels to about 900 m elevation. Changes in base level were greatest in the southern Interior Plateau and least in the Quesnel-Horsefly area. Base level fell significantly during the Pliocene and Quaternary, resulting in erosion of canyons and exhumation of older valleys that were previously buried. Post-Pliocene incision along Fraser River ranges from 200 m near Quesnel to more than 900 m near Big Bar Creek.
Landscape and Drainage Reconstructions

Physiography and waterways are reconstructed for several times spanning the last 100 Ma using bedrock geology, outcrop patterns, geomorphology and published stratigraphic information (Figs. 35-41). The times depicted are determined by major tectonic and depositional events in the study area: (1) Late Cretaceous to Paleocene (100-55 Ma), before Yalakom faulting; (2) early to middle Eocene (55-47 Ma), after Yalakom faulting and before Fraser faulting; (3) middle to late Eocene (47-33 Ma), during Fraser faulting; (4) Oligocene to middle Miocene (33-15 Ma), after Fraser faulting and before deposition of Chilcotin Group basalts; (5) middle to late Miocene (15-5 Ma), after deposition of Miocene flood basalts; (6) Pliocene to Pleistocene (5 Ma-10 ka), after regional uplift and during regional glaciation; and (7) the present. The reconstructions in Figures 35-41 show physiographic domains and drainage directions during these intervals. The main physiographic domains that are depicted are mountains, highlands, plains, and fluvio-lacustrine waterways.

Mountain terrain is rugged and is characterized by high relief and steep slopes. It is drained by a dense network of relatively low-order streams with steep gradients. Mountain terrain is rapidly eroded and soon loses all traces of older landscapes.

Highland terrain is rounded and is characterized by moderate relief and gentle to intermediate slopes. Highlands have sparse networks of streams with low gradients near their heads and steep gradients near their mouths. Highlands are subdivided into three units in Figures 35-41: highland developed in bedrock that is older than the interval depicted; igneous intrusive highland; and volcanic highland. Igneous highland is defined as terrain underlain by intrusive rocks of the same age as the interval depicted. This terrain type was elevated into hills by intruding rock masses. Most of this terrain remains as highland to this day, although on later time slices it is mapped as highland in older bedrock. Volcanic highland is terrain underlain by volcanic rocks of the same age as the interval depicted. It comprises low hills and irregular terrain with radial drainage near volcanic centres and disrupted drainage elsewhere. In later time frames, such terrain is mapped as highland in older bedrock.

Plains are areas of low relief. This domain includes plains and plateau areas, which are distinguished by their elevation with respect to the surrounding landscape and degree of drainage development. Plains occur at moderate to low elevations and support mature stream systems. Plateaus are found at moderate to high elevations and
typically have a poorly developed drainage network. Volcanic plains are underlain by Chilcotin Group basalts and valley basalts of Pliocene and Quaternary age.

Fluvio-lacustrine waterways are defined as valleys and basins of a variety of size and shape that are loci of sediment deposition. This domain is mapped wherever large basins and valleys retain stratigraphic evidence of being topographic depressions and containing rivers and lakes. Fluvio-lacustrine waterways occur mostly on plains, although they may extend into highlands. This terrain type is shown on Figures 35-41 by a site symbol superposed on other terrain types. Drainage directions are inferred from published paleocurrent and provenance data (Tables 4-6), or are inferred from regional slopes and other geomorphic information.

Cretaceous to Paleocene

Figure 35 is a schematic diagram depicting the landscape of southern British Columbia during Late Cretaceous to Paleocene time (100-55 Ma), before the onset of dextral strike-slip faulting along Yalakom and Fraser faults. Approximately 80 km of dextral strike-slip displacement along Fraser Fault and an equal amount along Yalakom Fault were removed to produce the scene in Figure 35.

Regional drainage was probably toward the north. Highlands occur in the present areas of the Coast, eastern Selkirk, Monashee and Quesnel mountains. Igneous highlands developed in the southeastern part of the study area, creating a northward-dipping regional slope. The Okanagan region probably was drained by north-flowing streams.

Early to middle Eocene

Figure 36 depicts the landscape after Yalakom faulting but before about 80 km of displacement along Fraser Fault, in the early to middle Eocene time (55 - 47 Ma). The restoration of displaced rocks along the Fraser Fault juxtaposes Cretaceous volcanic and sedimentary rocks of the Churn Creek – Gang Ranch area with Cretaceous Spences Bridge volcanic rocks between Cache Creek and Merritt (Fig. 36, piercing point A). Regional drainage was to the north and northwest along the regional slope of the central Interior Plateau. A fluvio-lacustrine waterway is mapped along the Clearwater-North Thompson River valley on the basis of middle Eocene strata on the present valley floor (circle 6, Fig. 25, Table 5). This north-draining waterway is interpreted to be
continuous with the valley extending from Quesnel and Cariboo lakes to Quesnel. The Okanagan region comprised highlands during this time, and drainage was likely toward the north.

Mountains or highlands existed in the Coast and Cascade Mountains and along the trace of the Yalakom Fault during early to middle Eocene time. The outcrop pattern of Cretaceous and Paleocene fluvial strata delineates rivers draining these highlands. The restored trend of Thompson River from Kamloops to Ashcroft is shown in Figure 36 to be coincident with the outcrop distribution of Eocene Churn Creek volcanic and sedimentary rocks, implying that the two areas were once a continuous depression (Fig. 36, grey dashed line). Drainage along Bridge and Seton rivers was northeastward.

**Middle to late Eocene**

Figure 37 depicts the landscape of southern British Columbia during 80 km of dextral strike-slip displacement along Fraser Fault in middle to late Eocene time (47-33 Ma). Steep relief developed along the trace of Fraser Fault. Ridges of igneous highland developed along Mission Ridge, Marshall Creek and other faults near Lillooet. Drainage along Bridge River and Seton Lake is interpreted to have been towards the southwest.

Regional drainage is to the north and northwest along the central, northwest-trending topographic depression of the central Interior Plateau and along North Thompson and Clearwater river valleys through Quesnel Lake to Quesnel. Extensive volcanic highlands developed throughout the region. Isolated basins developed in the Okanagan region. Drainage in that area is thought to have continued to the north, although it may have been disrupted in places by volcanism.

**Oligocene to middle Miocene**

Figure 38 depicts the landscape from 33 Ma to 15 Ma, after cessation of activity along the Fraser Fault and prior to deposition of most of the Chilcotin Plateau basalts. A few volcanic plains of limited extent developed at this time (Mathews, 1989). Mountains formed during the preceding period were worn down to highlands. An extensive area of low relief developed throughout Chilcotin and Cariboo plateaus and in Thompson Plateau and adjacent Okanagan Highland. Drainage in the Okanagan region is hypothesized to be northerly from about Summerland. Northward drainage is also inferred across Okanagan Highland (Mathews, 1988) and along North Thomson River
valley. Drainage was north- and northwestward in northern Thompson Plateau (Read, 2000) and northwestward from Quesnel Highlands across the Cariboo Plateau. This time period was one of regional erosion.

Bridge River and Seton Lake were cross-cut by Lillooet River valley, which follows the trend of the Owl Creek and Harrison Lake faults. A northeast- and north-flowing stream network is interpreted to have formed along the valleys of Stein, Nahatlatch, Nicola and lower Thompson rivers. Graded stream reaches support this conclusion (Tribe, 2003). There is some evidence for fluvial deposition in valleys parallel to the trace of Fraser Fault, for example between Big Bar Creek and Chilcotin River.

**Middle to late Miocene**

Figure 39 depicts the landscape from 15 Ma to 5 Ma, during and after eruption of Chilcotin Group basalts, and before the onset of regional uplift. A volcanic plain of low relief extends throughout the central Interior Plateau. This plain corresponds to the topographic depression that was the locus of deposition during the preceding period. Drainage is still northward in the Okanagan region. Eruption of flood basalts along stream courses and other topographic lows disrupted drainage (Mathews and Rouse, 1984).

**Pliocene to Pleistocene**

Figure 40 depicts the landscape and drainage pattern during regional uplift and development of the modern Coast Mountains (5 Ma-10 ka). Uplift occurred in the Coast and Cascade mountains and Pavilion Range. There is no evidence that uplift extended into central Thompson Plateau. Northeast-trending valleys were incised into the Chilcotin Plateau basalts by streams flowing from Hat Creek valley and Pavilion Ranges. A broad valley was carved in the plateau basalts from Clearwater Valley along Mahood and Canim lakes, thence northwestward toward Williams Lake. Southward drainage developed along Okanagan Valley south of Kelowna, and also in Kettle and Columbia river valleys.

A south-flowing Fraser River did not exist before headward erosion of a south-flowing stream near Hope captured the drainage of the Anderson, Nahatlatch and Stein rivers, and eventually much of the north-flowing drainage of southern British Columbia.
Conclusions

Geological cross-cutting relationships and an association of physiography with sedimentary paleoenvironments indicate that remnants of Cenozoic and possibly older valleys exist today in the southern Interior Plateau. Ages are assigned to some of the larger valleys based on geological relationships. Not all valleys and landforms are glacial in origin, although all have been modified by glacial erosion. Compelling evidence is given that most large valleys predate glaciation.

Regional base level is interpreted to have been relatively stable throughout the Interior Plateau during Late Cretaceous time. Base level fell 500-700 m between Late Cretaceous and middle Eocene time resulting in incision of valleys. The valleys filled with sediment to about 900 m elevation from the middle Eocene to Miocene. Base level fell after the Miocene, eroding canyons and exhuming older valleys that were previously partially buried. Changes in base level are greatest in the southern Interior Plateau and are least in the Quesnel-Horsefly area.

The development of physiography and drainage patterns has been reconstructed from geologic history and outcrop patterns. Regional drainage was northward throughout the Late Mesozoic and Tertiary. Streams drained northward along the central axis of the Interior Plateau, down the regional slope from highlands to the south. Restoration of Fraser and Yalakom fault displacements juxtaposes the valleys of Seton Lake and Bridge River with either Nicola Lake valley or Pasayten Group rocks near Hope. Southward drainage along Okanagan, Kettle, Thompson and Fraser rivers was not established until the Quaternary, possibly due to the influence of glaciation.

This research builds on decades of geologic mapping and speculation about drainage patterns. The conclusions reached here generally support previous interpretations of paleodrainage.

Future Work

Apatite (U-Th)/He thermochronometry will be used to determine the age of geomorphic surfaces in the study area. Apatite helium ages mark the time since the 70°C isotherm passed through the rock column. They are interpreted as the time of near-ground-surface cooling, thus yielding an approximation of exposure age. For example, physiography and geology suggest that the western Thompson Plateau and
southeastern Chilcotin Plateau retain a Late Cretaceous peneplain or erosion surface. In some places, this surface may have been exhumed, but in other places it was probably exposed throughout the last 100 Ma. If so, helium dates from these regions should be old.

Acknowledgments

John Clague and Bob Anderson reviewed the manuscript. This work was supported by an NSERC PGS-B scholarship, NSERC Earth Sciences Sector supplement, Simon Fraser University Fellowships and Clague's NSERC Operating Grant.
Figure 24. Index map of study area showing towns, streams, lakes, physiographic provinces and cross-section locations.
Figure 25. Shaded relief map of the western part of the study area showing locations of Cretaceous and Tertiary sedimentary rocks listed in Tables 4, 5 and 6, constructional volcanic landforms listed in Table 7 and cross-sections.
Figure 26. Shaded relief map of the eastern part of the study area showing locations of Cretaceous and Tertiary sedimentary rocks listed in Tables 4, 5 and 6, constructional volcanic forms listed in Table 7 and cross-sections.
Figure 27. Simplified geology and major faults in the study area. Older bedrock is not patterned.
Figure 28. Map showing the extent of planation surfaces and their limiting elevations.
Figure 30. Locations of sedimentary strata and volcanic centres that are projected onto each of the four transects in Figures 28-31.
Figure 31. Diagram showing the range of elevations of sedimentary strata of different age along the northern transect (Fig. 30) in the Quesnel, Horsefly and Shuswap areas.
Figure 32. Diagram showing the range of elevations of sedimentary strata of different age along the central transect (Fig. 30) in the vicinity of Gang Ranch, Pavilion and Vernon.
Figure 33. Diagram showing the range of elevations of sedimentary strata of different age along the southern transect (Fig. 30) in the vicinity of Pemberton, Nicola and Princeton.
Figure 34. Diagram showing the range of elevations of sedimentary strata of different age along the Fraser River transect (Fig. 30) from Quesnel to Hope.
Late Cretaceous to Paleocene
(100 - 55 Ma)
Pre-Yalakom and pre-Fraser faulting

Figure 35. Reconstructed physiography and drainage directions during Late Cretaceous to Paleocene time (ca. 100-55 Ma), before displacement along Yalakom and Fraser faults. Right-lateral displacement along these faults has been removed.
Figure 36. Reconstructed physiography and drainage directions during early to middle Eocene time (ca. 55-47 Ma), after Yalakom faulting but before Fraser faulting.
Middle to late Eocene (47 - 33 Ma) During Fraser Faulting

Figure 37. Reconstructed physiography and drainage directions during middle to late Eocene time (ca. 47-33 Ma), during displacement along Fraser Fault.
Figure 38. Reconstructed physiography and drainage directions during Oligocene to middle Miocene time (ca. 33-15 Ma), prior to deposition of the Chilcotin Plateau basalts.
Middle to late Miocene
(15 - 5 Ma)

Figure 39. Reconstructed physiography and drainage directions during middle to late Miocene time (ca. 15-5 Ma), after eruption of Chilcotin Plateau basalts.
Figure 40. Reconstructed physiography and drainage directions during Pliocene and Pleistocene time (ca. 5 Ma-10 ka).
Figure 41. Modern physiography and drainage directions.
Table 4. Middle Cretaceous to Paleocene nonmarine sedimentary rocks in southern British Columbia (Figs. 25, 26, squares).

<table>
<thead>
<tr>
<th>No.</th>
<th>Age, formation</th>
<th>Location</th>
<th>Brief description and paleoenvironment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Albian – Cenomanian, Dash-Churn succession</td>
<td>Churn Creek</td>
<td>Conglomerate and breccia deposited in a braided fluvial setting.</td>
<td>Schiarizza et al., 1997; Mahoney et al., 1999</td>
</tr>
<tr>
<td>2</td>
<td>Albian – Cenomanian, Churn Creek Conglomerate</td>
<td>Churn Creek</td>
<td>Chert-pebble conglomerate, sandstone; alluvial fan or braided stream setting with N to NW transport.</td>
<td>Green, 1990; Hickson et al., 1991; Riesterer et al., 2001</td>
</tr>
<tr>
<td>3</td>
<td>Cretaceous (?) – Paleocene, Flapjack Peak strata</td>
<td>Dash-Churn confluence</td>
<td>Polymictic conglomerate and sandstone deposited by braided streams with WSW to ENE transport.</td>
<td>Mahoney et al., 1999</td>
</tr>
<tr>
<td>4</td>
<td>Middle – Late Cretaceous, unnamed sediments</td>
<td>Pavilion</td>
<td>Gently-dipping, massive conglomerate, cross-bedded sandstone and shale deposited in a continental setting.</td>
<td>Bovis, 1985</td>
</tr>
<tr>
<td>5</td>
<td>Late Cretaceous, unnamed sediments</td>
<td>Drynoch</td>
<td>Shale, sandstone, and coal.</td>
<td>Van Dine, 1980; Bovis, 1985</td>
</tr>
<tr>
<td>6</td>
<td>Late Cretaceous, Churn Creek Formation</td>
<td>Koster Creek</td>
<td>180 m of mudstone, siltstone, sandstone and conglomerate deposited in a fluvial or lacustrine setting. Strata dip 35° to the north.</td>
<td>Green, 1990</td>
</tr>
<tr>
<td>7</td>
<td>Cenomanian – Turonian, Silverquick Formation</td>
<td>Taylor Creek; Mission Ridge</td>
<td>1500 m of conglomerate, sandstone and minor siltstone deposited by a west-flowing braided river.</td>
<td>Schiarizza et al., 1997</td>
</tr>
<tr>
<td>8</td>
<td>Cenomanian, Powell Creek Formation</td>
<td>Gun Creek</td>
<td>200 m of cobble conglomerate, tuffaceous sandstone, ash flow tuff and minor siltstone overlying older Silverquick Fm.</td>
<td>Schiarizza et al., 1997</td>
</tr>
<tr>
<td>9</td>
<td>Cenomanian – Turonian, Silverquick Formation</td>
<td>Hat Creek, Botanie Creek, Deadman River</td>
<td>Chert-pebble and polymictic conglomerate, sandstone and minor shale.</td>
<td>Journeay and Monger, 1994</td>
</tr>
<tr>
<td>No.</td>
<td>Age, formation</td>
<td>Location</td>
<td>Brief description and paleoenvironment</td>
<td>Reference</td>
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</tr>
<tr>
<td>10</td>
<td>Albian (?) to early Tertiary (?), unnamed unit</td>
<td>Quesnel Lake, Quesnel Forks</td>
<td>Conglomerate, sandstone, siltstone and mudstone deposited in a fluvial setting with provenance from the east.</td>
<td>Panteleyev et al., 1996</td>
</tr>
</tbody>
</table>
Table 5. Eocene sedimentary rocks in southern British Columbia (Figs. 25, 26, circles).

<table>
<thead>
<tr>
<th>No.</th>
<th>Age, formation</th>
<th>Location</th>
<th>Brief description and paleoenvironment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Eocene, unnamed</td>
<td>Siwhe Creek</td>
<td>1000 m of fault-bounded conglomerate, shale and sandstone deposited in fluvial and piedmont fan settings.</td>
<td>Duffell and McTaggart, 1952</td>
</tr>
<tr>
<td>2</td>
<td>Eocene, Jones Creek beds</td>
<td>Carpenter Lake</td>
<td>Gently dipping conglomerate, shale, sandstone and lignite bordered by faults to the northeast.</td>
<td>Schiariza et al., 1997</td>
</tr>
<tr>
<td>3</td>
<td>Eocene, Hat Creek Formation</td>
<td>Hat Creek</td>
<td>2000 m of fault-bounded sandstone, conglomerate and coal deposited in fluvial, marsh and lake settings.</td>
<td>Church, 1975; Read 2000</td>
</tr>
<tr>
<td>4</td>
<td>Eocene, Coldwater Formation</td>
<td>Nicola Valley</td>
<td>230 m of basal conglomerate, breccia, sandstone, shale and coal.</td>
<td>Cockfield, 1961</td>
</tr>
<tr>
<td>5</td>
<td>unnamed</td>
<td>Churn Creek - Big Bar</td>
<td>Conglomerate, clay, bentonite and lignite of south or west provenance.</td>
<td>Mathews and Rouse, 1984</td>
</tr>
<tr>
<td>6</td>
<td>Mid-Eocene, Chu Chua Formation</td>
<td>Chu Chua, Clearwater</td>
<td>800 m of conglomerate, sandstone, shale and coal deposited in fluvial and lacustrine settings.</td>
<td>Campbell and Tipper, 1971; Schiarizza and Preto, 1987</td>
</tr>
<tr>
<td>7</td>
<td>Mid-Eocene, Tranquille Formation</td>
<td>Kamloops Lake</td>
<td>500 m of lacustrine tuffaceous sandstone, siltstone and conglomerate dipping up to 35°.</td>
<td>Graham and Long, 1979; Ewing, 1981</td>
</tr>
<tr>
<td>8</td>
<td>McAbee Beds</td>
<td>McAbee- Savona</td>
<td>Mudflows and 130 m of lacustrine deposits.</td>
<td>Ewing, 1981</td>
</tr>
<tr>
<td>9</td>
<td>Middle Eocene</td>
<td>Horsefly - Quesnel</td>
<td>Lacustrine claystone, siltstone, sandstone, tuff and conglomerate with plant and freshwater fish fossils.</td>
<td>Panteleyev and Hancock 1988; Panteleyev et al., 1996</td>
</tr>
<tr>
<td>10</td>
<td>Middle Eocene</td>
<td>Horsefly</td>
<td>Fossil freshwater fish in lacustrine sediments.</td>
<td>Wilson, 1977</td>
</tr>
<tr>
<td>12</td>
<td>Eocene, Allenby Fm.</td>
<td>Hope</td>
<td>Fault-bounded conglomerate and sandstone with subvertical dips.</td>
<td>Monger, 1969</td>
</tr>
<tr>
<td>No.</td>
<td>Age, formation</td>
<td>Location</td>
<td>Brief description and paleoenvironment</td>
<td>Reference</td>
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</tr>
<tr>
<td>13</td>
<td>Middle Eocene, Princeton Group</td>
<td>Princeton</td>
<td>Sandstone, siltstone, coal and conglomerate with southward paleocurrents and freshwater fish fossils.</td>
<td>Preto, 1979; Wilson, 1982; Read, 2000</td>
</tr>
<tr>
<td>14</td>
<td>Eocene, Princeton Group</td>
<td>Princeton</td>
<td>300 m of horizontal conglomerate, sandstone, shale and coal with steep dips, in places.</td>
<td>Rice, 1947</td>
</tr>
<tr>
<td>16</td>
<td>Eocene, Allenby Fm.</td>
<td>Trapp Lake</td>
<td>No description available.</td>
<td>Journeay and Monger, 1994</td>
</tr>
<tr>
<td>17</td>
<td>Eocene</td>
<td>Spences Bridge</td>
<td>Sandstone, argillite and 2-m-thick coal seams. Age control is poor.</td>
<td>Duffell and McTaggart, 1952</td>
</tr>
<tr>
<td>18</td>
<td>Eocene</td>
<td>Keatley Creek</td>
<td>Cobble conglomerate.</td>
<td>Duffell and McTaggart, 1952</td>
</tr>
<tr>
<td>19</td>
<td>Eocene</td>
<td>Botanie Creek</td>
<td>Small coal occurrences. Locations uncertain.</td>
<td>Duffell and McTaggart, 1952</td>
</tr>
<tr>
<td>20</td>
<td>Eocene</td>
<td>Ferguson Creek</td>
<td>Small occurrence. Location uncertain.</td>
<td>Duffell and McTaggart, 1952</td>
</tr>
<tr>
<td>21</td>
<td>Eocene</td>
<td>Cache Creek</td>
<td>Sandstone, shale and coal.</td>
<td>Duffell and McTaggart, 1952</td>
</tr>
<tr>
<td>22</td>
<td>Eocene</td>
<td>S. Thompson River</td>
<td>No description available.</td>
<td>Okulitch, 1979</td>
</tr>
<tr>
<td>23</td>
<td>Eocene, White Lake Formation</td>
<td>Kelowna</td>
<td>Mudstone, sandstone and conglomerate onlap the Black Knight and Mt Boucherie dacite.</td>
<td>Bardoux, 1985</td>
</tr>
<tr>
<td>26</td>
<td>Eocene, White Lake Formation</td>
<td>White Lake</td>
<td>Up to 1000 m of sandstone, conglomerate, coal interbedded with volcanic rocks.</td>
<td>Church, 1973</td>
</tr>
<tr>
<td>No.</td>
<td>Age, formation</td>
<td>Location</td>
<td>Brief description and paleoenvironment</td>
<td>Reference</td>
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</tr>
<tr>
<td>27</td>
<td>Eocene</td>
<td>Vernon, Lavington</td>
<td>Conglomerate associated with massive volcanic rocks unconformably overlying older bedrock.</td>
<td>Thompson and Daughtry, 1994</td>
</tr>
<tr>
<td>28</td>
<td>Eocene outlier</td>
<td>Enderby Cliffs, Trinity Hills</td>
<td>Fluvial and lacustrine sandstone, siltstone, shale and conglomerate with east, northeast or southeast provenance.</td>
<td>Mathews, 1981</td>
</tr>
<tr>
<td>29</td>
<td>Eocene</td>
<td>Rock Creek</td>
<td>No description available.</td>
<td>Journeay et al., 2000b</td>
</tr>
<tr>
<td>30</td>
<td>Eocene ?</td>
<td>unnamed</td>
<td>Sedimentary strata not described.</td>
<td>Okulitch, 1979</td>
</tr>
<tr>
<td>31</td>
<td>Eocene, Springbrook Formation</td>
<td>Ollala, Brent Lake</td>
<td>Boulder conglomerate and talus unconformably overlying bedrock.</td>
<td>Bostock, 1941; Church, 1973.</td>
</tr>
<tr>
<td>33</td>
<td>Eocene?</td>
<td>Harris Creek</td>
<td>Polymictic conglomerate, shale and sandstone.</td>
<td>Church and Suesser, 1983</td>
</tr>
<tr>
<td>34</td>
<td>Eocene</td>
<td>Deadman River</td>
<td>Conglomerate and sandstone of a fan delta.</td>
<td>Read, 1988b, 2000</td>
</tr>
</tbody>
</table>
Table 6. Oligocene, Miocene and Pliocene sediments in southern British Columbia (Figs. 25, 26, stars).

<table>
<thead>
<tr>
<th>No.</th>
<th>Age, formation</th>
<th>Location</th>
<th>Brief description and paleoenvironment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Early Oligocene, Australian Creek Formation</td>
<td>Quesnel, Narcosli Creek</td>
<td>Mudstone, sandstone, conglomerate and lignite; deposited in lake, swamp, alluvial fan and north-flowing braided stream settings in a valley parallel to Fraser Fault, strata tilted and locally folded.</td>
<td>Rouse and Mathews, 1979; Long and Graham, 1993</td>
</tr>
<tr>
<td>2</td>
<td>Middle Miocene, Fraser Bend Formation</td>
<td>Quesnel</td>
<td>150 m of flat-lying fluvial and lacustrine conglomerate, sandstone, siltstone, claystone and minor lignite. Paleo flow direction was to the south, provenance was from east, northeast and north.</td>
<td>Rouse and Mathews, 1979</td>
</tr>
<tr>
<td>3</td>
<td>Middle Miocene, Fraser Bend Formation</td>
<td>Gang Ranch, Watson Bar Creek</td>
<td>300 m of conglomerate and sandstone; provenance to the north and east; fluvial and backswamp paleoenvironment.</td>
<td>Mathews and Rouse, 1984; Green, 1990; Read, 2000</td>
</tr>
<tr>
<td>4</td>
<td>Miocene, Horsefly placers</td>
<td>Quesnel Horsefly River</td>
<td>Fluvial channels containing white quartz pebble conglomerate with source to the east.</td>
<td>Levson and Giles, 1993; Panteleyev et al., 1996</td>
</tr>
<tr>
<td>5</td>
<td>Miocene (?), unnamed strata</td>
<td>Empire Valley</td>
<td>Fluvial conglomerate and sandstone; northwest transport.</td>
<td>Green and Trupia, 1989; Green, 1990; Read, 2000.</td>
</tr>
<tr>
<td>6</td>
<td>Miocene, Deadman River Formation</td>
<td>Bonaparte, Deadman Rivers</td>
<td>Ash, tuff, diatomaceous sandstone, siltstone and shale; fluvial paleoenvironment; flow to north and west.</td>
<td>Read, 2000</td>
</tr>
<tr>
<td>7</td>
<td>Middle Miocene, unnamed sediments</td>
<td>Coldstream, Wood Lake,</td>
<td>Weakly cemented gravel paleochannel above 900 m and parallel to Wood Lake; flow direction unknown; correlated with Fraser Bend Formation.</td>
<td>Church and Suesser, 1983; Mathews, 1988; 1991</td>
</tr>
<tr>
<td>8</td>
<td>Late (?) Miocene, unnamed sediments</td>
<td>Blizzard Property,</td>
<td>Sandstone, mudstone and conglomerate; paleochannel exhibits incised meanders; thalweg at 1240-1340 m elevation.</td>
<td>Mathews, 1988, 1991</td>
</tr>
</tbody>
</table>

115
<table>
<thead>
<tr>
<th>No.</th>
<th>Age, formation</th>
<th>Location</th>
<th>Brief description and paleoenvironment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Middle Miocene, Crownite Formation</td>
<td>Quesnel, Narcosli Creek</td>
<td>12-m-thick diatomite; paleoenvironment is broad valley with shallow lakes between low hills.</td>
<td>Rouse and Mathews, 1979</td>
</tr>
<tr>
<td>10</td>
<td>Pliocene, unnamed sediments</td>
<td>Empire Valley, Leon Creek</td>
<td>90 m of conglomerate, sandstone and minor siltstone underlying 2.4 Ma basalt flow.</td>
<td>Mathews and Rouse, 1984</td>
</tr>
</tbody>
</table>
Table 7. Documented constructional volcanic landforms and eruptive centres in southern British Columbia (Figs. 25, 26, triangles).

<table>
<thead>
<tr>
<th>No.</th>
<th>Age, formation</th>
<th>Location</th>
<th>Estimated elevation, m</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Triassic, Nicola Group</td>
<td>Near Princeton</td>
<td>1300-1600</td>
<td>No description available</td>
<td>Preto, 1979</td>
</tr>
<tr>
<td>2</td>
<td>Early Cretaceous, Spences Bridge Group</td>
<td>Prospect Creek</td>
<td>900-1100</td>
<td>Shield volcano</td>
<td>D. Thorkelson, pers. comm., 2001</td>
</tr>
<tr>
<td>3</td>
<td>Early Cretaceous, Spences Bridge Group</td>
<td>Nicoamen River</td>
<td>900-1800</td>
<td>Shield volcano</td>
<td>D. Thorkelson, pers. comm., 2001</td>
</tr>
<tr>
<td>4</td>
<td>Early Cretaceous, Spences Bridge Group</td>
<td>Shovelnose Mountain</td>
<td>1000-1650</td>
<td>Flow-banded rhyolite</td>
<td>Cockfield, 1961</td>
</tr>
<tr>
<td>5</td>
<td>Eocene, Kamloops Group</td>
<td>Cache Creek</td>
<td>1200</td>
<td>Rhyolite dome</td>
<td>Church, 1975; Read, 2000</td>
</tr>
<tr>
<td>6</td>
<td>Eocene, Kamloops Group</td>
<td>North of Tranquille</td>
<td>800-1200</td>
<td>Kissick and Doherty cones, tuff rings</td>
<td>Ewing, 1981</td>
</tr>
<tr>
<td>7</td>
<td>Eocene, unnamed volcanic rocks</td>
<td>Black Dome Mountain</td>
<td>950-1300</td>
<td>Possible central vent area</td>
<td>Hickson, 1992</td>
</tr>
<tr>
<td>8</td>
<td>Early Miocene, Coquihalla Volcanic Complex</td>
<td>Coquihalla Mountain</td>
<td>1300-2000</td>
<td>Eroded volcanic centre</td>
<td>Mathews et al., 1981</td>
</tr>
<tr>
<td>9</td>
<td>Early Miocene, Coquihalla Volcanic Complex</td>
<td>Podunk Creek centre</td>
<td>1322-1800</td>
<td>Eroded volcanic centre</td>
<td>Mathews et al., 1981</td>
</tr>
<tr>
<td>10</td>
<td>Early-middle Miocene, Pemberton Volcanic Belt</td>
<td>Stein River</td>
<td>1200-2500</td>
<td>Eroded volcanic centres</td>
<td>Souther, 1991</td>
</tr>
<tr>
<td>11</td>
<td>Miocene-Pliocene, Chilcotin Group</td>
<td>Big Creek</td>
<td>1100-1300</td>
<td>Eruptive centre</td>
<td>Hickson et al., 1991</td>
</tr>
<tr>
<td>No.</td>
<td>Age, formation</td>
<td>Location</td>
<td>Estimated elevation, m</td>
<td>Description</td>
<td>Reference</td>
</tr>
<tr>
<td>-----</td>
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<td>---------------------------------</td>
<td>------------------------</td>
<td>------------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>12</td>
<td>Late Miocene, Chilcotin Group</td>
<td>Lone Butte, Forestry Hill</td>
<td>1200</td>
<td>Two gabbroic plugs</td>
<td>Farquharson, 1973; Bevier, 1983</td>
</tr>
<tr>
<td>13</td>
<td>Late Miocene, Chilcotin Group</td>
<td>Mount Begbie</td>
<td>1200</td>
<td>Gabbroic plugs</td>
<td>Farquharson, 1973; Bevier, 1983</td>
</tr>
<tr>
<td>14</td>
<td>Late Miocene, Chilcotin Group</td>
<td>Skoal Point</td>
<td>1500-1600</td>
<td>Gabbroic plugs</td>
<td>Farquharson, 1973; Bevier, 1983</td>
</tr>
<tr>
<td>15</td>
<td>Late Miocene, Chilcotin Group</td>
<td>Tin Cup Mountain</td>
<td>1200</td>
<td>Gabbroic plugs</td>
<td>Farquharson, 1973; Bevier, 1983</td>
</tr>
<tr>
<td>16</td>
<td>Miocene, Chilcotin Group</td>
<td>Deadman River</td>
<td>1200-1300</td>
<td>Possible eruptive centre</td>
<td>Read, 2000</td>
</tr>
<tr>
<td>17</td>
<td>Miocene-Pliocene, Chilcotin Group</td>
<td>Alkali Lake</td>
<td>950-1050</td>
<td>Possible eruptive centre</td>
<td>Read, 1992</td>
</tr>
<tr>
<td>18</td>
<td>Miocene-Pliocene, Chilcotin Group</td>
<td>Gaspard Creek</td>
<td>1100-1300</td>
<td>Eruptive centre</td>
<td>Hickson et al., 1991</td>
</tr>
<tr>
<td>19</td>
<td>Pliocene-Pleistocene, volcanic rocks</td>
<td>Word Creek</td>
<td>1400-1100</td>
<td>Possible eruptive centre</td>
<td>Hickson et al., 1991</td>
</tr>
<tr>
<td>20</td>
<td>Quaternary, Garibaldi Volcanic Belt</td>
<td>Garibaldi Mountain</td>
<td>1100-2500</td>
<td>Eroded volcanic edifice</td>
<td>Green et al., 1988</td>
</tr>
<tr>
<td>21</td>
<td>Quaternary, Clearwater Volcanic Group</td>
<td>Pyramid Mountain</td>
<td>830-1079</td>
<td>Volcanic cones</td>
<td>Hickson, 1986</td>
</tr>
<tr>
<td>22</td>
<td>Quaternary, Clearwater Volcanic Group</td>
<td>Spanish Creek</td>
<td>1200-1740</td>
<td>Volcanic cones</td>
<td>Hickson, 1986</td>
</tr>
<tr>
<td>23</td>
<td>Quaternary, Lambly Creek Flow</td>
<td>Kelowna</td>
<td>1160</td>
<td>Volcanic centre</td>
<td>Mathews, 1988</td>
</tr>
</tbody>
</table>
CHAPTER SIX
CONCLUSIONS

The southern Interior Plateau of British Columbia is an ancient landscape produced by river erosion and tectonic processes over the last 100 million years and modified by glaciation during the Neogene. Anomalous geomorphology, valley-fill geology, cross-cutting relationships and the distribution of unconformities indicate that the area retains relict or exhumed landforms of Late Cretaceous and early Cenozoic age.

The development of physiography and drainage patterns was inferred from geologic history and outcrop patterns. Ages were assigned to some of the large valleys and landforms based on geological and structural relationships. Reconstructions of landscapes and waterways are presented for several time intervals spanning the last 100 million years. Compelling evidence is given that many large valleys predate glaciation.

Drainage anomalies, such as valley-floor divides, underfit streams and graded valley segments, provide information on former base levels in the landscape. Regional base level was relatively stable at 1000-1300 m elevation throughout the region south of 52°N during the Mesozoic. North of this latitude, in the Quesnel-Horsefly area, base level was stable, but lower than farther south (700-1000 m elevation) during the Mesozoic. From Late Cretaceous to middle Eocene time, base level fell 500-700 m, accompanied by incision of valleys. Some valleys filled with sediments to an elevation of about 900 m from middle Eocene to Miocene time. Following the Miocene, base level fell, and valleys that were previously partially buried were eroded or exhumed. Changes in base level are greatest in the southern Interior Plateau and are least in the Quesnel-Horsefly area.

Regional drainage was northward throughout much of the Cenozoic. Streams drained along the central axis of the Interior Plateau from highlands in the south. Northward drainage across southern Interior Plateau also is inferred from the outcrop pattern of Miocene-Pliocene Chilcotin basalt flows. An anabranching valley system
extending from Quesnel and Shuswap highlands across Cariboo Plateau to Fraser River valley contained north-flowing streams that date back to the Eocene and possibly Late Cretaceous. Other valleys dating to middle Eocene time and possibly earlier are those of North Thompson River south of Clearwater, Thompson River from Kamloops to Spences Bridge, Nicola Lake, Hat Creek, and Okanagan Valley north of Penticton.

The oldest preserved valleys in the southern Coast Mountains are those of ancestral Bridge and Seton rivers, which are interpreted to have formed during the Late Cretaceous to Eocene before strike-slip faulting. Restoration of displacement along the Fraser and Yalakom faults juxtaposes the valleys of Seton Lake and Bridge River with either Nicola Lake valley or Pasayten Group rocks near Hope. Lillooet River valley crosscut, and captured the headwaters of, ancestral Bridge and Seton rivers.

A dendritic network of streams in the Coast Mountains was superimposed on older drainage patterns in the Oligocene and Miocene. Lower Thompson River, Nahatlatch River, Stein River and Mowhokam Creek define an east-flowing stream system that must postdate activity on Fraser Fault and predate the south-flowing Fraser River. This drainage pattern was active some time between Eocene and Pliocene time. This inference suggests that a northeast-dipping regional slope from Coast Mountains to Thompson Plateau was maintained in this region following Eocene strike-slip faulting.

Fraser River valley south of Macalister is younger than the valley to the north and developed after late Miocene time. Regional uplift during late Miocene-Pliocene time caused streams to incise their valleys. Valleys were widened and deepened by glaciation. Southward drainage along Okanagan, Kettle, Thompson and Fraser rivers was not established until the late Pliocene or early Quaternary, possibly due to the influence of glaciation.

This research builds on a century of geologic mapping and geomorphic speculation, and generally supports previous interpretations of paleodrainage. Thesis research indicates that large regions of the landscape in the study area evolved slowly or hardly changed at all. Great changes in terrain elevation or relief tend to occur in narrow or localized areas along stream courses or fault traces. Tectonic effects on landscape evolution have not been considered much in this thesis. One aim of the work was to display the landscape as accurately as possible, and focus on observable and mappable features without speculating too much about tectonic causes and effects.
Apatite (U-Th)-He ('helium') thermochronology can be used to determine the age of geomorphic surfaces. This low-temperature isotopic clock measures the time since rocks cool beneath 70°C, thus giving the time since the rock was near the ground surface. Apatite helium dating could provide an independent, quantitative, analytical test of the conclusions reached in this thesis. For example, I have concluded that a Late Cretaceous (ca. 100 million year old) peneplain or erosion surface is preserved in western Thompson Plateau and southeastern Chilcotin Plateau. In some places, the surface may have been exhumed. Elsewhere, it was probably exposed throughout the last 100 Ma. Helium ages of rocks sampled from these surfaces should yield a Mesozoic age. Apatite fission track ages ranging from 80 Ma to 102 Ma have been found in southwest British Columbia by L. Currie (Pers. comm., 2002). The closure temperature for apatite fission tracks is 100°C, which corresponds to a depth of about 4 km, assuming a constant geothermal gradient of 25°C/km. Fission track data suggest that less than 4 km of vertical exhumation has occurred in this region during the last 100 Ma or so.
REFERENCES


APPENDIX A
SUPPLEMENTAL GEOLOGICAL MAPS

Fifteen maps display regional geology on a shaded relief background for key areas in the study area. They provide a detailed depiction of bedrock geology and physiography, and supplement the figures in the body of the thesis.

A simplified geological legend is used for the maps. Geology is from digital compilations (Journeay and Williams, 1995; Journeay and Monger, 1998) and from British Columbia Geological Survey digital files available from The Map Place (http://www.em.gov.bc.ca/Mining/Geolsurv/MapPlace/). Some of the maps have bands of missing geology. This is due to gaps and overlap inconsistencies in the original digital geology files from the British Columbia Geological Survey. Detailed information and constituent formations can be found in Geological Survey of Canada maps and reports listed in the references, and from the digital sources listed above.
Figure 42. Index map.
Figure 43. Hope area.

Legend

- Qs: Quaternary sedimentary rock
- Qv: Quaternary volcanic rock
- P: Pliocene
- P: Pliocene volcanic rock
- MP: Miocene-Pliocene sedimentary rock
- MPv: Miocene-Pliocene volcanic rock
- Ms: Miocene sedimentary rock
- Mv: Miocene volcanic rock
- M: Miocene plutonic rock
- Os: Oligocene sedimentary rock
- Ov: Oligocene volcanic rock
- Op: Oligocene plutonic rock
- E: Eocene sedimentary rock
- Ev: Eocene volcanic rock
- Ep: Eocene plutonic rock
- Pp: Paleocene plutonic rock
- Ks: Cretaceous sedimentary rock
- Kv: Cretaceous volcanic rock
- Kp: Cretaceous plutonic rock
- KTp: Cretaceous-Tertiary pluton
- Gn: Metamorphic rock
- Js: Jurassic sedimentary rock
- Trv: Triassic volcanic rock
- Mz: Mesozoic and older sedimentary & plutonic rock
- Mzp: Mesozoic and older plutonic rock

/// Fault: defined, approximate, inferred
Figure 44. Lytton area.

Legend

Gs Quaternary sedimentary rock
Qv Quaternary volcanic rock
Pv Pliocene volcanic rock
MPs Miocene-Pliocene sedimentary rock
MPv Miocene-Pliocene volcanic rock
Ms Miocene sedimentary rock
Mv Miocene volcanic rock
Mp Miocene plutonic rock
Os Oligocene sedimentary rock
Ov Oligocene volcanic rock
Op Oligocene plutonic rock
Es Eocene sedimentary rock
Ev Eocene volcanic rock
Ep Eocene plutonic rock
Pp Paleocene plutonic rock
Ks Cretaceous sedimentary rock
Kv Cretaceous volcanic rock
Kp Cretaceous plutonic rock
KTp Cretaceous-Tertiary pluton
Js Jurassic sedimentary rock
Trv Triassic volcanic rock
Mz Mesozoic and older sedimentary & plutonic rock
Mz p Mesozoic and older plutonic rock
/// Fault: defined, approximate, inferred
Figure 45. Nicola Lake - Merritt area.

Legend

- **Qs**: Quaternary sedimentary rock
- **Qv**: Quaternary volcanic rock
- **Pv**: Pliocene volcanic rock
- **MPs**: Mio-Pliocene sedimentary rock
- **MPv**: Mio-Pliocene volcanic rock
- **Ms**: Miocene sedimentary rock
- **Mv**: Miocene volcanic rock
- **Mp**: Miocene plutonic rock
- **Os**: Oligocene sedimentary rock
- **Ov**: Oligocene volcanic rock
- **Op**: Oligocene plutonic rock
- **Ee**: Eocene sedimentary rock
- **Ev**: Eocene volcanic rock
- **Ep**: Eocene plutonic rock
- **Pp**: Paleocene plutonic rock
- **Ks**: Cretaceous sedimentary rock
- **Kv**: Cretaceous volcanic rock
- **Kp**: Cretaceous plutonic rock
- **Ktp**: Cretaceous-Tertiary pluton
- **Js**: Jurassic sedimentary rock
- **Trv**: Triassic volcanic rock
- **Mz**: Mesozoic and older sedimentary & plutonic rock
- **Mzp**: Mesozoic and older plutonic rock

/// Fault: defined, approximate, inferred
Figure 49. Big Bar area.
Figure 50. Gang Ranch area.
Legend

Qs  Quaternary sedimentary rock
Qv  Quaternary volcanic rock
Pv  Pliocene volcanic rock
MPs  Mio-Plio sedimentary rock
MPv  Mio-Plio volcanic rock
Ms  Miocene sedimentary rock
Mp  Miocene plutonic rock
Os  Oligocene sedimentary rock
Ov  Oligocene volcanic rock
Op  Oligocene plutonic rock
Es  Eocene sedimentary rock
Ev  Eocene volcanic rock
Pp  Paleocene plutonic rock
Ks  Cretaceous sedimentary rock
Kv  Cretaceous volcanic rock
Kp  Cretaceous plutonic rock
Js  Jurassic sedimentary rock
Trv  Triassic volcanic rock
Mz  Mesozoic and older sedimentary & plutonic rock
Mzp  Mesozoic and older plutonic rock

/// Fault: defined, approximate, inferred
Legend

Qs Quaternary sedimentary rock
Qv Quaternary volcanic rock
Pv Pliocene volcanic rock
MPs Mio-Plio sedimentary rock
MPv Mio-Plio volcanic rock
Ms Miocene sedimentary rock
Mv Miocene volcanic rock
Mp Miocene plutonic rock
Os Oligocene sedimentary rock
Ov Oligocene volcanic rock
Op Oligocene plutonic rock
Es Eocene sedimentary rock
Ev Eocene volcanic rock
Ep Eocene plutonic rock
Pp Paleocene plutonic rock
Ks Cretaceous sedimentary rock
Kv Cretaceous volcanic rock
Kp Cretaceous plutonic rock
KTP Cretaceous-Tertiary pluton
Js Jurassic sedimentary rock
Jv Jurassic volcanic rock
Gn Metamorphic rock
Mz Mesozoic and older sedimentary & plutonic rock
Mzp Mesozoic and older plutonic rock

/// Fault: defined, approximate, inferred