Eocene paleo-physiography and drainage directions, southern Interior Plateau, British Columbia[1]

Selina Tribe

Abstract: A map of reconstructed Eocene physiography and drainage directions is presented for the southern Interior Plateau region, British Columbia south of 53°N. Eocene landforms are inferred from the distribution and depositional paleoenvironment of Eocene rocks and from crosscutting relationships between regional-scale geomorphology and bedrock geology 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 the Cariboo Plateau to the Fraser River valley, contained north-flowing streams from Eocene to early Quaternary time. Other valleys dating back at least to Middle Eocene time include the 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 early 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.

Résumé : Cet article présente une carte reconstituée de la géographie physique et des directions de drainage, à l'Éocène, pour la région du plateau intérieur de la Colombie-Britannique, au sud du 53^{e} parallèle Nord. Les formes de terrain à l'Éocène sont déduites de la distribution et du paléoenvironnement de déposition des roches de l'Éocène et à partir de relations de recoupement entre la géomorphologie à l'échelle régionale et la géologie du socle, d'âge connu. Les directions de drainage à l'Éocène sont déduites de la géographie physique, du relief et des élévations du niveau de base de la discordance sub-Éocène ainsi que de documentations sur la distribution, la provenance et les paléocourants de sédiments fluviaux au Cénozoïque précoce. À l'Éocène, le paysage du plateau intérieur sud ressemble à sa contrepartie moderne avec des terres hautes, des plaines et un drainage très encaissé, sauf que le drainage régional était vers le nord. De l'Éocène jusqu'au Quaternaire précoce, un système de vallées à bras de rivière anastomosés, à tendance ouest et nord-ouest à partir des terres hautes de Quesnel et de Shuswap, à travers le plateau de Cariboo, jusqu'à la vallée de la rivière Fraser, contenait des ruisseaux s'écoulant vers le nord. D'autres vallées remontant au moins jusqu'à l'époque de l'Éocène moyen comprennent la vallée de la rivière Thompson Nord au sud de Clearwater, la vallée de la rivière Thompson de Kamloops à Spences Bridge, la vallée contenant le lac Nicola, la vallée de la rivière Bridge et la vallée du lac Okanagan. Au cours du Cénozoïque précoce, des terres hautes existaient là où se situe la chaîne Côtière actuelle. Le drainage vers le sud le long des vallées des rivières modernes Fraser, Chilcotin et Thompson a été établi après le Miocène tardif.

[Traduit par la Rédaction]

Introduction

The early Cenozoic was a tectonically active time in southern British Columbia, and the landscape of the time probably reflected the volcanism and faulting that was occurring. However, the relationship between tectonic activity and geomorphic development is not well understood. This is reflected in the somewhat vague, current model of physiographic evolution for the Interior Plateau, which 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. Across this landscape were deposited widespread calc-alkaline volcanic rocks of Eocene age and scattered sediments in extensional basins (Tipper 1971; Mathews 1991).

Throughout the last century, many geologists have recognized the antiquity of parts of the present-day landscape and

Received 25 March 2004. Accepted 6 July 2004. Published on the NRC Research Press Web site at http://cjes.nrc.ca on 14 March 2005.

Paper handled by Associate Editor J. Jin.

S. Tribe. BGC Engineering Inc., Suite 500, 1045 Howe Street, Vancouver, BC V6Z 2A9, Canada (e-mail: stribe@bgcengineering.ca).

[1]This article is one of a selection of papers published in this Special Issue on *The Okanagan Highlands: Eocene biota, environments, and geological setting*.

commented on the age and origin of rivers and valleys throughout the Interior Plateau. For example, 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 angle 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). The North Thompson – Clearwater river valley and other major drainage systems in southwestern British Columbia were established before Eocene time (Campbell and Tipper 1971), as evidenced by 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 outlines the regional development of physiography in the period leading up to, and during, Eocene time. I present a detailed reconstruction of Eocene landscapes and drainage patterns in the southern Interior Plateau and provide estimates of that landscape's relief and base level elevation. The reconstruction is based on regional-scale geomorphic domains observed on high-resolution shaded relief maps combined with a synthesis of lithologic, stratigraphic, structural, and fossil data documented by others. The resulting paleo-physiographic map is a graphic depiction of physiography during Eocene time. It supports many of the conclusions reached by previous workers (Uglow 1923; Lay 1941; Tipper 1971; Fulton 1975; Mathews 1991; Read 2000) and provides the physical setting for biotic evolution reported by others in this issue of *Canadian Journal of Earth Sciences*.

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. 1). 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. 1; Holland 1976; Mathews 1986). Shaded relief maps of the study area (Figs. 2, 3) 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.

The highlands and plateaus are dissected by valleys of differing size and orientation. Drainage is broadly south and southwest along the Fraser, Thompson, Okanagan, and Kettle rivers and their tributaries (Fig. 1). Exceptions to southward drainage are the Shuswap River, which flows northwest through a series of lakes to the 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 modern-day stream drainage is not adjusted to the landscape and that some valleys may be relicts from an earlier time (Tribe 2002, 2003).

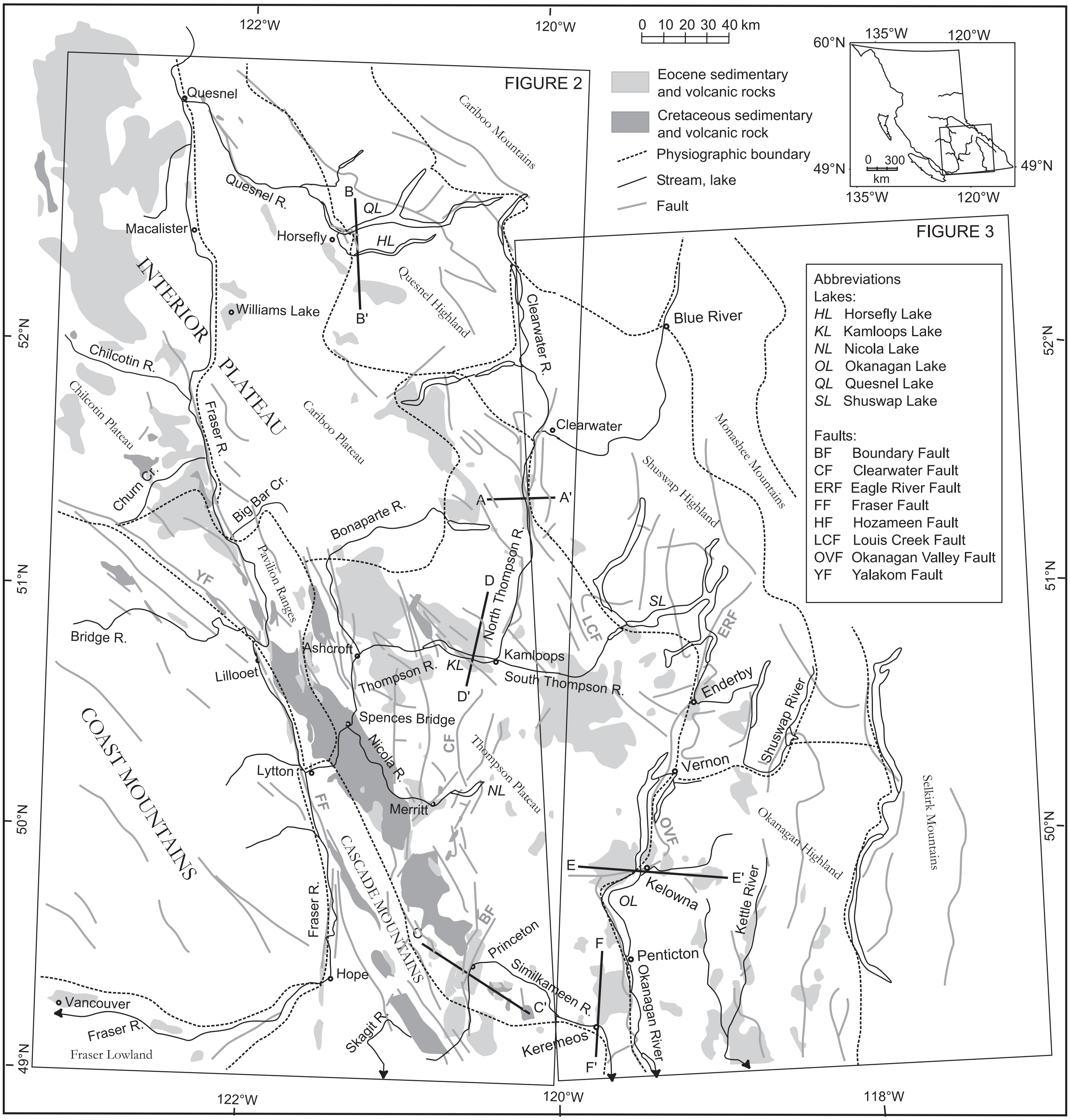
Bedrock geology

Landscapes of the southern Interior Plateau developed in Paleozoic to Jurassic volcanic, sedimentary, metamorphic, and plutonic rocks (Fig. 1, white areas; Monger 1989; Campbell and Tipper 1971). The area underwent compressional and extensional deformation during the Paleozoic and Mesozoic. The Louis Creek fault, among others, may have been active during the Mesozoic. North-trending faults, such as the Okanagan Fault, Eagle River Fault, and numerous others (labelled on Fig. 1 and visible as prominent lineaments on Fig. 3; Monger and Price 1979; Monger et al. 1982; Brown and Journeay 1987) were active during Paleogene extension. Bedrock in the southern Coast Mountains comprises 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. 1; Mathews 1991). The sub-Cretaceous unconformity is preserved in the Thompson, Cariboo, and Chilcotin plateaus; neighbouring Cascade and Pavilion ranges; and the northeasternmost portion of the Coast Mountains in the study area but has not been observed throughout the Okanagan Highland and at the eastern margin of the Interior Plateau (Fig. 1). The sub-Cretaceous unconformity is overlain primarily by Spences Bridge Group volcanic rocks. Scattered exposures of Cretaceous fluvial conglomerate and sandstone, some containing north-trending 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. 1). 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. 1). In the Princeton area, Allenby Formation sed-

Fig. 1. Map of study area showing towns, rivers, lakes, physiographic regions (upper case Times Roman), and sub-regions (lower case Times Roman), cross-section locations, and locations of Figs. 2 and 3. Also shown are terrestrial deposits of Cretaceous (dark grey) and Eocene (light grey) age, including subaerial volcanic flows, air-fall deposits, and fluvial and lacustrine sediments. Regional faults are shown as grey lines. Bedrock geology from Journeay and Williams (1995) and Journeay and Monger (1998).



imentary 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. 1). These faults include the northwest-trending Yalakom and Hozameen faults of Late Cretaceous to Paleogene age (Schiarizza et al. 1997) and the crosscutting Fraser Fault, which was active 47–35 Ma ago with 80–120 km of dextral strike-slip (labelled on Fig. 1; Monger 1989; Coleman and Parrish 1991). Normal and strike-slip faults on the Thompson Plateau and Okanagan Highland, some with northeast or east strikes, are related to dextral strike-slip faulting and the development of grabens

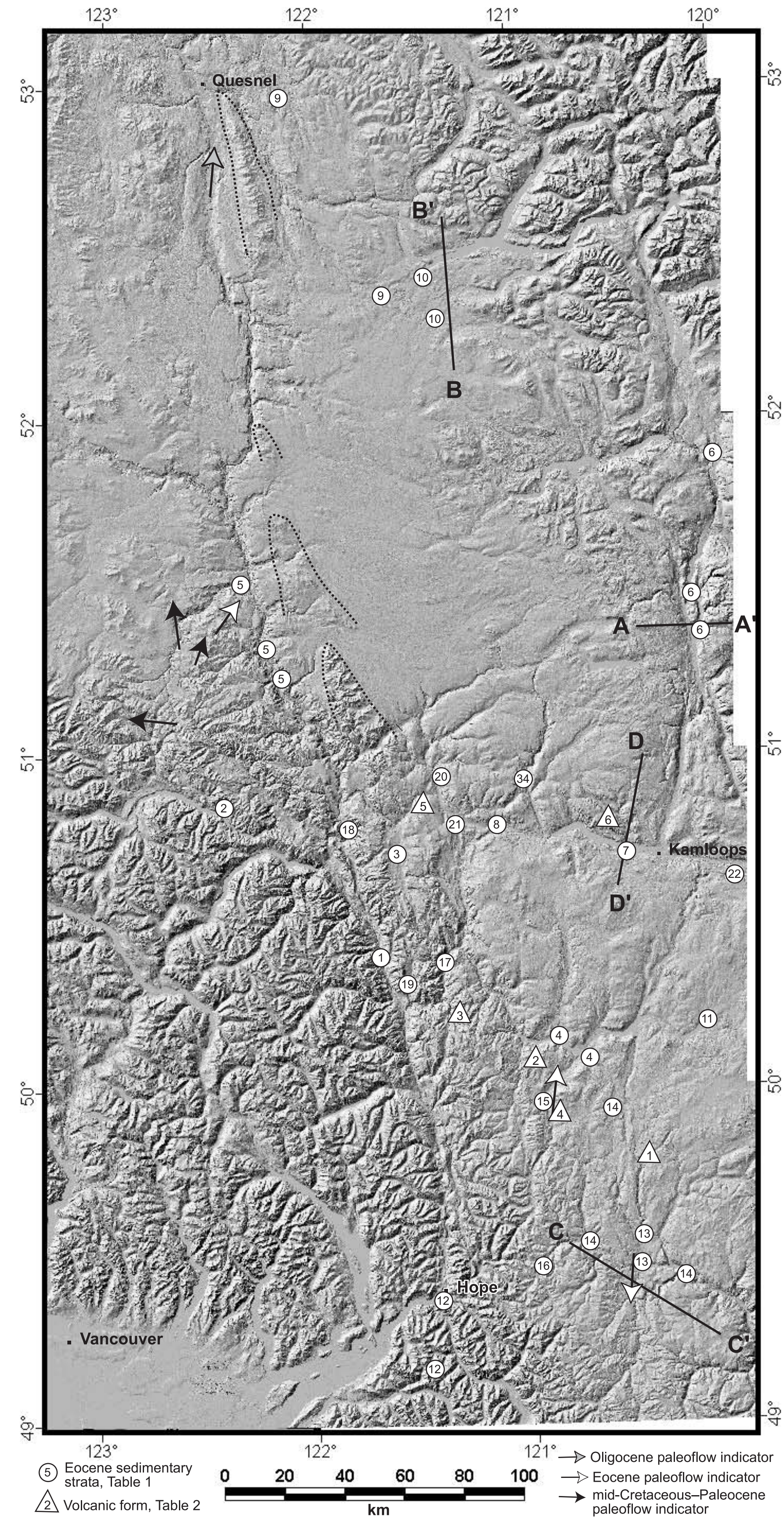

123°
122°
121°
120°
53°
52°
51°
50°
49°
Quesnel
Kamloops
Hope
Vancouver
B'
B
A
A'
D
D'
C
C'
0 20 40 60 80 100
km
Eocene sedimentary strata, Table 1
Volcanic form, Table 2
Oligocene paleoflow indicator
Eocene paleoflow indicator
mid-Cretaceous–Paleocene paleoflow indicator

Fig. 2. Shaded relief map of the western study area showing the locations of documented Eocene sedimentary rocks (circles, Table 1), paleoflow indicators (arrows), constructional volcanic forms (triangles, Table 2), and cross-sections. Dotted lines delineate topographic highs referred to in the text. Light source is located in the northwest at 45° above the horizon.

and half-grabens during Paleogene time (Fig. 1; Monger 1985). The Fraser River valley and parts of the 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.

Sub-Miocene and younger unconformities (not shown in Fig. 1) 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 in scattered locations on the Okanagan Plateau (Mathews 1988). Flat-lying Miocene–Pliocene Chilcotin basalts are widespread on the northern Thompson, Cariboo, and Chilcotin plateaus and the Okanagan Highland (Mathews 1988, 1989). Pliocene and Quaternary basalt flows are confined to valleys near Merritt, Kelowna, and Clearwater (Hickson 1986). During the Quaternary, the study 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 paleoenvironments 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 1). 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 Paleogene age. An exception is the Hat Creek area, where Eocene sediments postdate the onset of Eocene volcanism (Read 2000). Although in places Eocene sedimentary rocks are 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). If Eocene sediments were more extensive, a marked unconformity would separate the sediments from the overlying volcanic strata. Such an unconformity is not observed.

The distribution of Eocene sedimentary rocks is shown in Figs. 2 and 3. Eocene sedimentary rocks almost exclusively are found in large valleys or topographic depressions (Figs. 2, 3, circles) throughout the study area. 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. 1, 2) flows along an unusually broad valley, where it is first a natural lake and then an underfit stream. It also contains sedimentary records of fluvial and lacustrine environments. The association of Eocene fluvial, lacustrine, and paludal deposits in poorly drained, large valleys is evidence for the antiquity of the valleys.

Documented Eocene or older constructional volcanic landforms, such as domes, shields, and cones (Table 2, Fig. 2), provide additional evidence that the landscape retains some early Cenozoic forms. Volcanic landforms of Eocene age occur north of Kamloops Lake and Ashcroft on the northwestern Thompson Plateau (V5, V6, Table 2, Fig. 2). 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 and even Triassic age persist (V1–V4, Table 2, Fig. 2).

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 lowest 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 sedimentary strata (Figs. 4, 5) and from geologic cross-sections (Fig. 6). Cross-sections also show the configuration of the sub-Eocene unconformity and provide estimates of paleotopographic relief (Fig. 6). 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 throughout the study area shows that Eocene rocks have the lowest position in the landscape (Figs. 4, 5). Eocene sedimentary rocks (Fig. 5, grey) range from 200 to 1400 m elevation, with most strata between 400 to 1200 m. Throughout the study area, older Late Cretaceous to Paleocene strata are elevated several hundred metres above Eocene strata (Fig. 5). This suggests that Eocene base level dropped with respect to earlier base levels, which caused incision of streams into the older surface and resulted in significant topographic relief (Fig. 7).

In many places Eocene relief was similar in magnitude and location to modern relief. Relief of 400 to over 1000 m is seen in profiles across the Thompson Plateau (Fig. 6). 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 1, Fig. 2), giving an estimate of 1300 m relief on the sub-Eocene unconformity (Fig. 6A). This range of values is similar in magnitude to a reported 600 m of paleo-relief on the sub-Eocene unconformity in the southwest Arrowstone Hills near Cache Creek (Read 1988*a*).

Near Horsefly Lake, Middle Eocene volcanic and lacus-

Table 1. Documented Eocene sedimentary strata shown on Figs. 2 and 3.

Site No.	Age; formation	Location	Brief description and paleoenvironment	Reference
1	Mid-Eocene	Siwhe Creek	1000 m of fault-bounded conglomerate, shale, sandstone in fluvial and piedmont fan setting	Duffell & McTaggart (1952)
2	Eocene; Jones Creek beds	Carpenter Lake	Gently northeast-dipping conglomerate, shale, sandstone, and lignite. Fault bounded to northeast	Schiarizza et al. (1997)
3	Eocene; Hat Creek Fm	Hat Creek	2000 m of conglomerate, sandstone, coal; fluvial, marsh, and lake settings; fault-bounded	Church (1975); Read (2000)
4	Eocene; Coldwater Fm	Nicola Valley	230 m of basal conglomerate, breccia, sandstone, shale, and coal	Cockfield (1961)
5	Eocene	Churn Creek – Big Bar	Conglomerate, clay, bentonite, and lignite. South or west provenance	Mathews & Rouse (1984)
6	Mid-Eocene; Chu Chua Fm	Chu Chua, Clearwater	800 m of conglomerate, sandstone, shale, and coal. Fluvial and lacustrine paleoenvironment	Campbell & Tipper (1971); Schiarizza & Preto (1987)
7	Mid-Eocene; Tranquille Fm	Kamloops Lake	500 m of lacustrine tuffaceous sandstone, siltstone, and conglomerate dipping 0°–35°	Graham & Long (1979); Ewing (1981)
8	Eocene; McAbee Beds	McAbee–Savona	Mudflows and 130 m of lacustrine deposits	Ewing (1981)
9	Mid-Eocene	Horsefly– Quesnel	Lacustrine clay, silt, sandstone, tuff, and conglomerate. Plant, freshwater fish fossils	Panteleyev et al. (1996); Panteleyev & Hancock (1988)
10	Mid-Eocene	Horsefly	Fossil freshwater fish in lacustrine sediments	Wilson (1977)
11	Eocene	Chapperon Lake	Eocene sediments with abundant petrified wood	Fulton (personal communication, 2003); Cockfield (1961)
12	Eocene; Allenby Fm	Hope	Fault-bounded cobble conglomerate, sandstone; strata folded with subvertical dips	Monger (1969)
13	Mid-Eocene; Princeton Gp	Princeton	Sandstone, siltstone, coal, conglomerate. Southerly paleocurrents; freshwater fossil fish	Preto (1979); Wilson (1982), Read (2000)
14	Eocene; Princeton Gp	Princeton	300 m of horizontal conglomerate, sandstone, shale, and coal. Steep dips in places	Rice (1947)
15	Eocene	Kingsvale	2000 m of conglomerate, sandstone; north-flowing braided streams. Strata dip 25°–40°	Thorkelson (1989)
16	Eocene; Allenby Fm	Trapp Lake	No description available	Journeay & Monger (1994)
17	Eocene?	Spences Bridge	Sandstone, argillite, and coal; coal seam is 2 m thick. Age control poor	Duffell & McTaggart (1952)
18	Eocene?	Keatley Creek	Cobble conglomerate	Duffell & McTaggart (1952)
19	Eocene?	Botanie Creek	Small coal occurrences. Location uncertain	Duffell & McTaggart 1952
20	Eocene?	Ferguson Creek	Small occurrence. Exact location uncertain	Duffell & McTaggart (1952)
21	Eocene?	Cache Creek	Outlier of sandstone, shale, and coal	Duffell & McTaggart (1952)
22	Eocene?	South Thompson R.	Sedimentary strata not described	Okulitch (1979)
23	Eocene; White Lake Fm	Kelowna	Mudstone, sandstone, conglomerate onlap Black Knight and Mt. Boucherie dacite	Bardoux (1985)
24	Eocene; White Lake Fm	Joe Rich Klippe	Steeply dipping breccia unconformably overlying gneiss	Bardoux (1985)
25	Eocene; White Lake Fm	Summerland	Fluvial and lacustrine sediments overlying Eocene volcanic rocks in Summerland caldera	Church et al. (1991)

Table 1 (*concluded*).

Site No.	Age; formation	Location	Brief description and paleoenvironment	Reference
26	Eocene; White Lake Fm	White Lake	Up to 1000 m of sandstone, conglomerate, coal, and plant fossils interbedded with volcanics	Church (1973)
27	Eocene	Vernon, Lavington	Conglomerates associated with massive volcanics unconformably overlying older bedrock	Thompson & Daughtry (1994)
28	Eocene outlier	Enderby Cliffs, Trinity Hills	Fluvial and lacustrine sandstone, siltstone, shale and conglomerate with minor coal, locally fossiliferous; east, northeast or southeast provenance	Mathews (1981); Breitsprecher (2002)
29	Eocene	Rock Creek	No description available	Journeay et al. (2000)
30	Eocene?	unnamed	Sedimentary strata not described	Okulitch (1979, 1989)
31	Eocene; Springbrook Fm	Ollala, Brent Lake	Boulder conglomerate, talus unconformable upon an older bedrock surface of steep relief	Bostock (1941); Church (1973)
32	Eocene?	Adams Lake	Conglomerate. Strata not described	Schiarizza & Preto (1987)
33	Eocene?	Harris Creek	Conglomerate, shale, and sandstone	Church & Suesser (1983)
34	Eocene	Deadman River	Conglomerate, grit; possible fan–delta deposit	Read (1988*b*, 2000)

Note: Fm, Formation; Gp, Group.

trine strata crop out in a broad valley, 35 km wide and about 500 m deep, carved in Paleozoic and Mesozoic bedrock (Fig. 6B). Eocene sediments (sites 9, 10 in Table 1, Fig. 2) and Late 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 and are incised about 200 m below the broad valley floor. The coincidence of the sub-Eocene and sub-Miocene unconformities on the valley floor near Horsefly Lake (Fig. 6B) 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, into which Eocene volcanic and sedimentary rocks of the Princeton Group (sites 13, 14 in Table 1, Fig. 2) 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. 6C).

In the Kamloops Lake area (Fig. 6D), the sub-Eocene unconformity delineates a broad depression at least 15 km wide carved into 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 about 450 m on the south shore of Kamloops Lake and rises to about 750 m to the south (Fig. 6D). The depression can be traced along the Thompson River valley from Kamloops to Ashcroft, where it is 480–650 m and coincident with the floor of the Ashcroft strath (Tribe 2003).

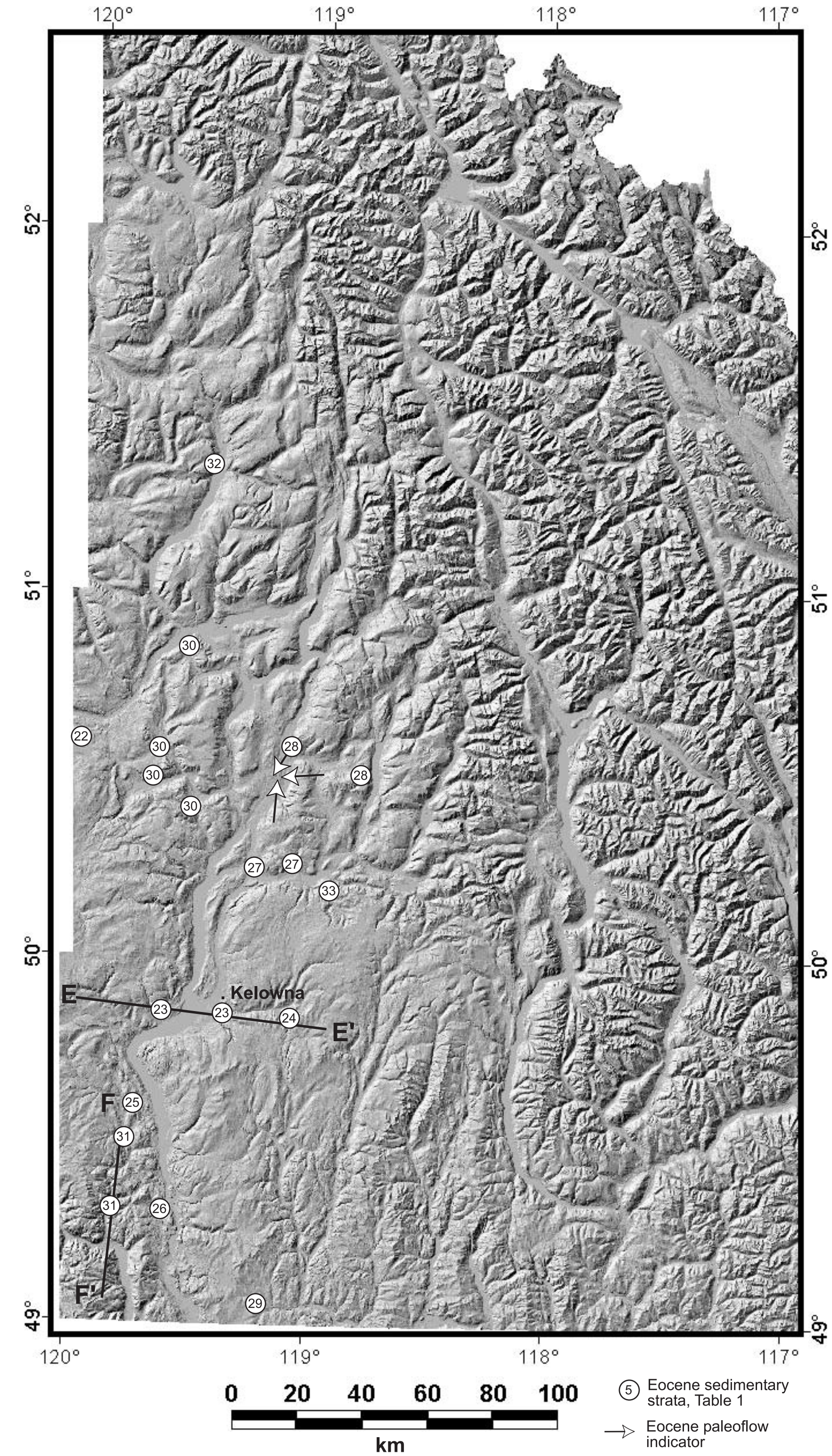
Across Okanagan Valley, near and north of Kelowna, Eocene base level was 350–500 m elevation, as defined by flanking Eocene strata at Mount Boucherie and Black Knight Mountain (Fig. 6E) and by Eocene strata near Enderby. At Kelowna (Fig. 6E), the sub-Eocene unconformity defines a broad 30 km-wide valley, in which sediments of the Eocene White Lake Formation (Es in Fig. 6E; site 23 in Table 1, Fig. 3) were deposited near 400 m elevation. On both sides of the valley, the unconformity rises to over 1000 m elevation and parallels the present-day highland and plateau surfaces (Figs. 6E, 8). 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 Table1, Fig. 3; 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. 6F; site 31, Table 1, Fig. 2).

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. 2; Schiarizza et al. 1997; Mahoney et al. 1999; Riesterer et al. 2001). Near Churn Creek along the Fraser River, conglomerates with provenance to the west and south indicate a north-flowing stream in Paleogene time (Fig. 2; Mathews and Rouse 1984). South of Merritt, pebble imbrication indicates Eocene streams flowed northward along Fig Lake Graben valley toward Merritt (Fig. 2, site 15; Thorkelson 1989).

The exception to broadly northward paleoflow is the Allenby Formation sediments in the Princeton area, which have southward paleocurrents and northern provenance indicating a south-flowing stream during Middle Eocene time (Fig. 2, site 13; Read 2000). Read (1988*a*) describes what he interprets to be a fan–delta deposit in the northern Thompson Plateau between Kamloops and Ashcroft (Fig. 2, site

Fig. 3. Shaded relief map of the eastern study area showing the locations of documented Eocene sedimentary rocks (circles, Table 1), paleoflow indicators (arrows), and cross-sections. Light source is located in the northwest at 45° above the horizon.



34). No paleocurrent indicators or provenance data were given, but the implied flow direction is westward (Read 1988*a*). In the Okanagan Valley near Trinity Hills, clasts in Eocene sediments have a provenance to the north, northeast and south (Fig. 3, site 28; Mathews 1981).

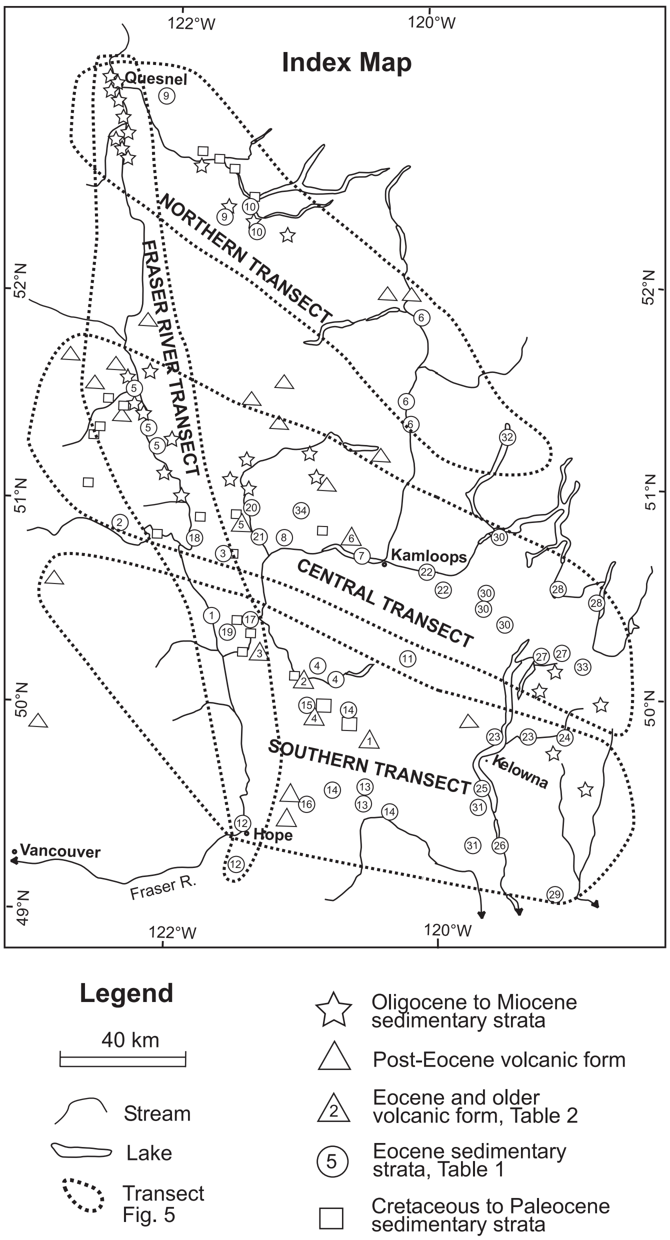
Paleo-physiographic domains

Eocene landscape and drainage directions (Fig. 9) 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.

Table 2. Documented Eocene and older constructional volcanic forms shown on Fig. 2.

Site No.	Age; formation	Location	Description	Reference
1	Triassic; Nicola Gp	Near Princeton		Preto (1979)
2	Cretaceous; Spences Bridge Gp	Prospect Creek	Shield volcano	Thorkelson (personal communication, 2001)
3	Cretaceous; Spences Bridge Gp	Nicoamen River	Shield volcano	Thorkelson (personal communication, 2001)
4	Cretaceous; Spences Bridge Gp	Shovelnose Mountain	Flow-banded rhyolite	Cockfield (1961)
5	Eocene; Kamloops Gp	Cache Creek	Rhyolite dome	Read (2000), Church (1975)
6	Eocene; Kamloops Gp	North of Tranquille	Kissick and Doherty cones, tuff rings	Ewing (1981)

Fig. 4. Index map of transects shown in Fig. 5. All sedimentary rocks (symbols) within the dotted lines are projected onto profiles shown in Fig. 5.



The main physiographic domains depicted are mountains, highlands, plains, and fluvio-lacustrine waterways.

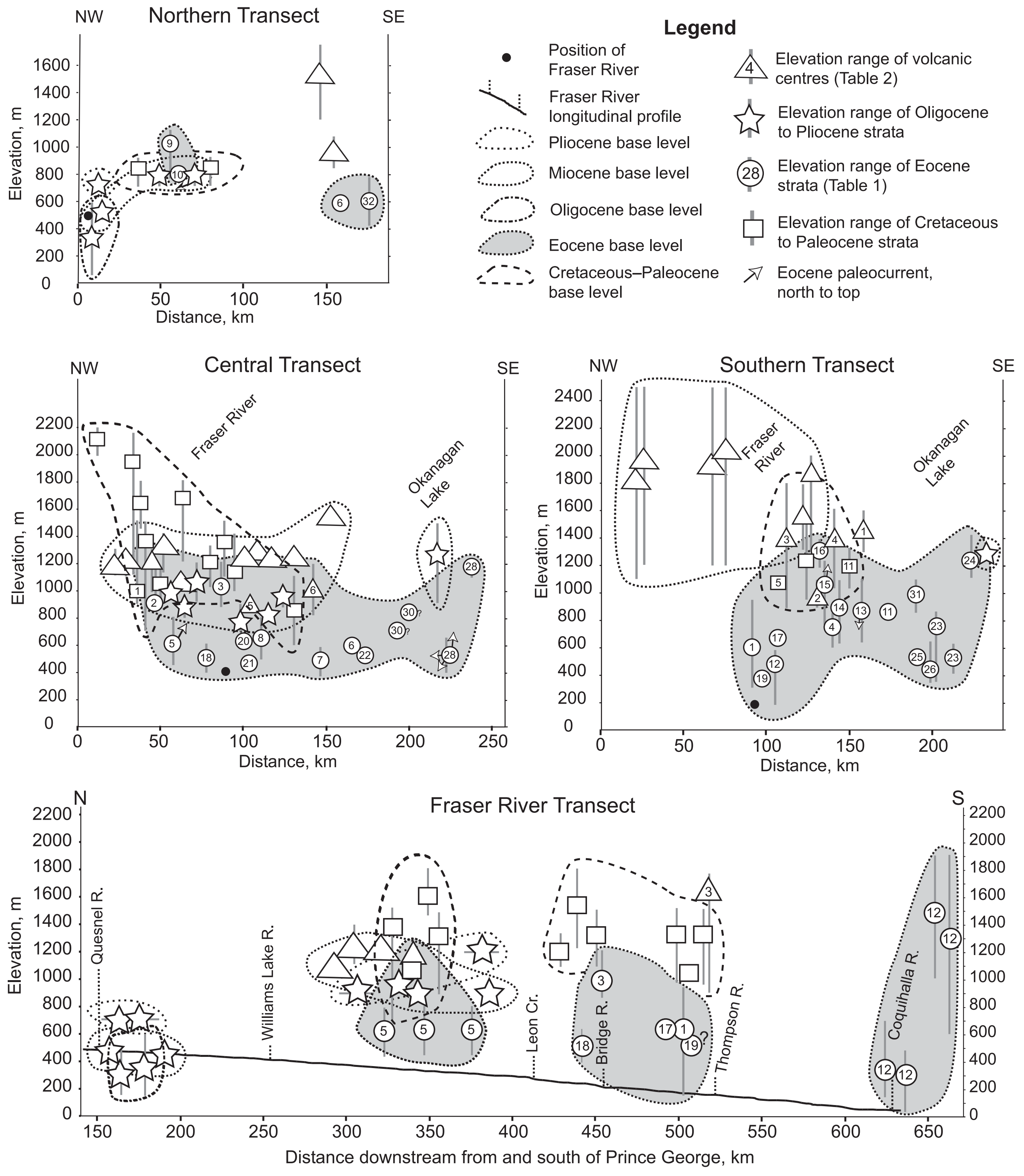
Mountains (Fig. 9, "peak" pattern) are characterized by high relief and steep slopes. They are drained by a dense network of relatively low-order streams with steep gradients. Mountains experience active erosion and have lost all traces of older landscapes. Modern mountain physiography is seen in the Coast Mountains (Fig. 2, 121.75°W, 49.75°N) and Selkirk Mountains (Fig. 3, 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 Fig. 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. 3, 119°W, 49.5°N) and Shuswap Highland (Fig. 3, centred at 119.25°W, 51.2°N).

Plateaus and plains (Fig. 9, 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 usually poor. Cariboo Plateau (Fig. 2, 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. 2, 120.5°W, 50°N) is an example of a plateau: a flat area elevated above the regional drainage network, which flows in canyons and incised valleys several hundreds of metres below the plateau surface.

Fluvio-lacustrine waterways (Fig. 9, black dots) are mapped wherever large basins and valleys retain stratigraphic evidence of rivers and lakes. They represent valleys and basins that were the 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 mapped as a site symbol that may superpose over other domains. Drainage directions are inferred from published stratigraphic information, regional slopes, and other geomorphic information. Modern fluvio-lacustrine waterways

Fig. 5. Diagrams showing the elevation range of sedimentary strata of different age along four transects outlined in Fig. 4. The elevation range of Eocene sedimentary strata is shaded grey. Vertical exaggeration 80 ×. Modified from Tribe (2004).



include the upper Thompson River valley along 50.75°N (Fig. 2) and Okanagan Valley along 119.5°W (Fig. 3).

Eocene landscape reconstruction

The resulting map of paleo-physiographic domains provides a graphic representation of the Eocene landscape (Fig. 9). 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. 1, FF and YF) was on the wane or had ceased (Monger 1989; Coleman and Parrish 1991). The Eocene physiography of southwest-

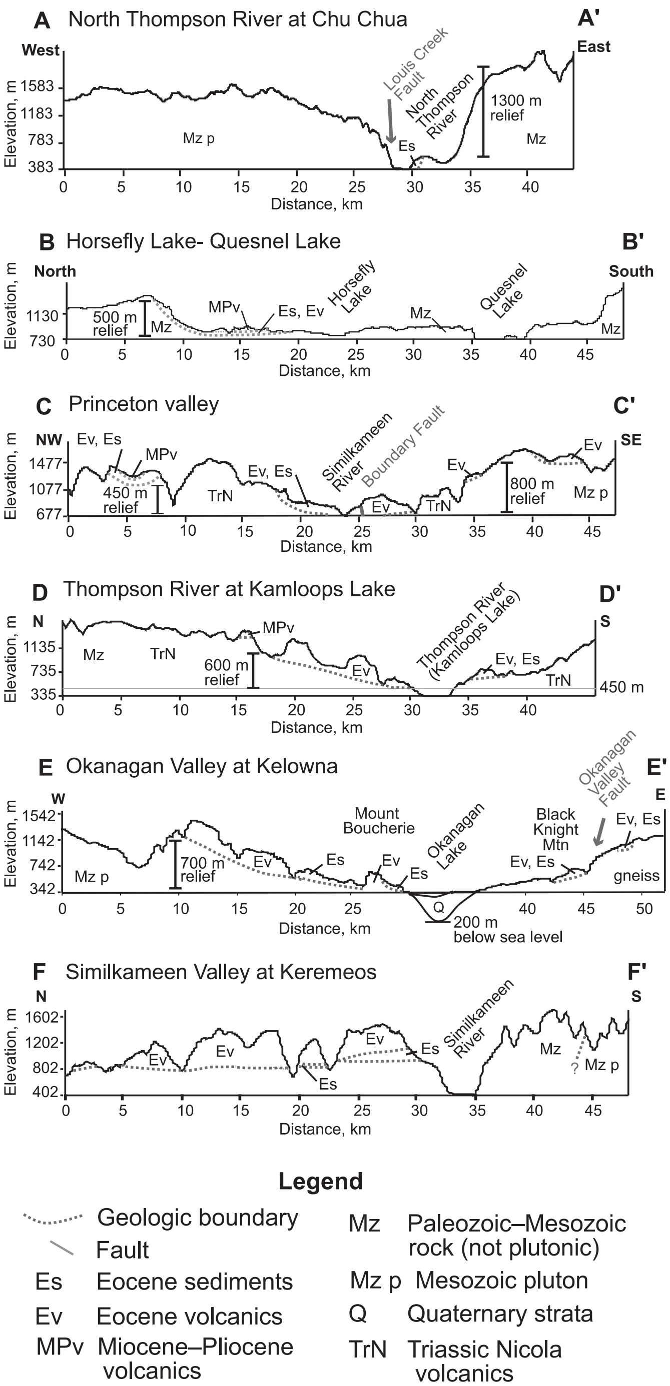


Fig. 6. Geologic cross-sections showing the sub-Eocene and sub-Miocene unconformities. Vertical bars on sections A, B, C, and E denote the amount of relief on the sub-Eocene unconformity. Section locations shown in Figs. 1, 2, and 3. Geology from Bostock (1941), Ewing (1981), Bardoux (1985), Journeay and Monger (1994), 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 5 ×.

ern British Columbia bears some semblance 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 modern values.

Highlands and mountains in the region east of Kamloops existed 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 in the region of the modern southern Coast Mountains also existed 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 that require overlying bedrock into which they could 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. 2, black arrows; Schiarizza et al. 1997; Mahoney et al. 1999; Riesterer et al. 2001) also support the existence of highlands in the region to the south.

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 Late 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 the 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 the Fraser River valley near Macalister (Tribe 2004). The valley system retains traces of Eocene fluvial and lacustrine deposits (sites 9, 10 on Fig. 2, Table 1) and is mapped as a fluvio-lacustrine waterway in Fig. 9. A profile of the valley system near Horsefly is shown in Fig. 6B.

Plains or lowlands eroded into older bedrock existed in the regions known today as Thompson, Cariboo, and Chilcotin plateaus. The plain continues to the northwest and was the corridor for regional northward drainage during early Cenozoic time. The physiography of southernmost Chilcotin Plateau and northwest Pavilion Range (Fig. 2, 122.25°W, 51.2°N) suggests the 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 mid- and 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

Fig. 7. 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.

Fig. 8. View from Kelowna looking south along Okanagan Lake. Mount Boucherie, the rounded hill in center 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.

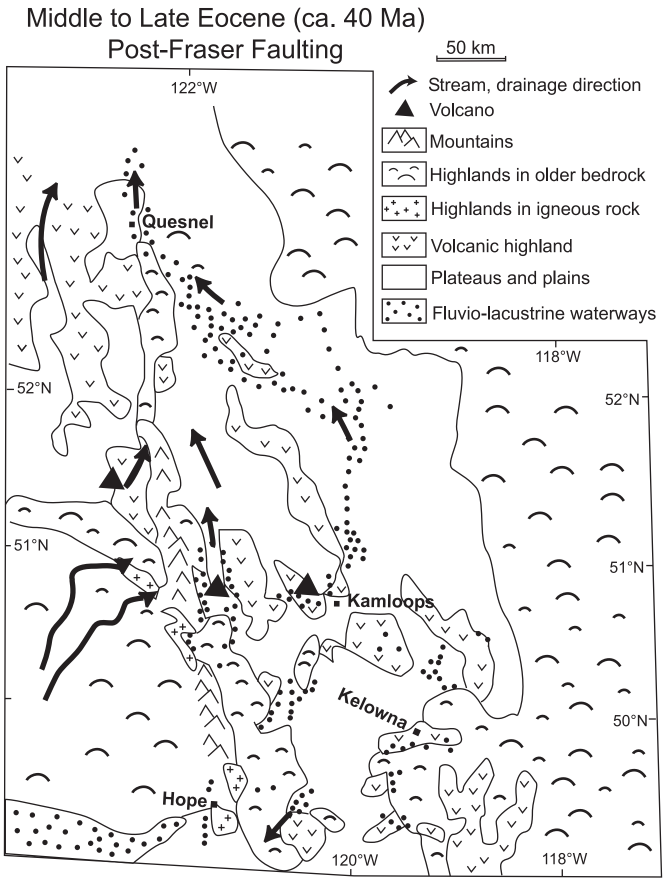
in the Eocene sedimentary record distinguishes the Eocene as a time of ponded and disrupted drainage. No lacustrine or coal-bearing rocks are known from earlier deposits, and they are uncommon in the Miocene sedimentary record. Eocene sedimentary strata are located near modern base level, and throughout 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. 2, dotted outline) are parallel to, and east of, the Fraser Fault. The high areas close to the north-northwest and flare open to the southeast (Fig. 2). Their configuration resembles a fold set plunging to the north. 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 Late Cretaceous through Eocene time by activity on the nearby Fraser Fault. Near Churn and Big Bar creeks, Miocene Chilcotin basaltic flows were controlled 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 trace and received thick sequences of coarse sediments. Near Big Bar Creek (site 5 in Table 1, Fig. 2), geologic relationships indicate the Eocene Fraser River valley was buried by 600 m of sediment between Eocene and Miocene time.

The anabranching fluvio-lacustrine waterway trending northwest from Shuswap and Quesnel highlands (Fig. 9) joins the Fraser River valley near Macalister, a point where the Fraser valley changes from a mature broad valley in the north to a narrow rock-walled canyon in the south (Fig. 2). In the northern study area near Quesnel, the elevation range of Oligocene, Miocene, and Pliocene strata exceed one another in stratigraphic order (Fig. 5, 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 valley near Quesnel indicate north-flowing streams in Early Oligocene time (Fig. 2; Rouse and Mathews 1979; Long and Graham 1993). These relationships imply that the Fraser River valley north of Macalister is early Cenozoic or possibly late Mesozoic in age, in contrast to the south, where the valley is late Cenozoic in age.

Fig. 9. Reconstructed physiography and drainage directions during Eocene time about 40 million years ago.



Like the Fraser River, Thompson River is another example of a modern stream flowing along a valley with a two-stage developmental history. Upstream of Spences Bridge, modern Thompson River is underfit for its valley, which is interpreted to be Eocene age 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. 2, Table 1; Duffell and McTaggart 1952), which corresponds roughly to the elevation of the floor of the broad Eocene depression from Kamloops to Spences Bridge. Thus, downstream of Spences Bridge, modern Thompson River valley is younger than Eocene as evidenced by an indicator of Eocene base level stranded 400 m above modern river level.

There is no consensus regarding the structural origin and Eocene history of Okanagan Valley. The valley is thought by some to be the trace of a north-trending, low-angle detachment fault that brought Paleogene gneiss to the surface in Eocene time (Templeman-Kluit and Parkinson 1986). The increase in metamorphic grade from west to east across the valley, and Eocene cooling dates from high-grade rocks east of the valley, support this view. Others note that the sub-Eocene surface is an unconformity rather than a fault and consider the gneiss to be older, perhaps Jurassic in age (Bardoux 1985; Thompson and Daughtry 1994). They consider the northern Okanagan Valley near Vernon to be a half-graben or graben with extension of about 1 km. Both views can be reconciled if the northern part of the valley has a different structural history than the southern part. Alternatively, the valley could have undergone some measure of detachment faulting in the Eocene followed by local normal faulting (A. Okulitch, personal communication, 2004). In either case, it is unlikely that extensional faulting formed the central valley depression to the depth it has today. Geomorphic observations presented here suggest that Okanagan Valley in part has a fluvial or subaerial origin and was not caused solely by extensional detachment faulting.

The reconstructed Eocene landscape depicts highlands at the site of the present-day southern Coast Mountains (Fig. 9), 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 the Fraser Fault. Her data depict the southern Coast Mountains as a northwest-trending core of rapidly rising, cooling topography with young fission track ages of 8–18 Ma, surrounded by successively older terrain with fission-track ages up to 115 Ma.

In contrast to studies that infer Eocene relief in the southern Coast Mountains (Parrish 1983; Reiners et al. 2002; L. Currie, unpublished data, 2002), apatite (U–Th)/He ages in the central Coast Mountains at 54°N are interpreted as evidence of young (ca. 4 Ma) topographic relief (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 the range has today. However, they discard that interpretation and adopt the assumption of intense glacial incision, which leads to their preferred interpretation of young, 4 Ma-old relief in the central Coast Mountains.

The preservation of Eocene and older landforms suggests only modest glacial erosion on a regional scale. This is in contrast to the interpretation that landscape in the study area is relatively young and resulted from glacial erosion and deposition throughout the Quaternary and possibly the Late Pliocene. These two views may be reconciled somewhat by defining the scale of inquiry. The deposits of multiple glaciations and evidence of glacial erosion are visible in many places throughout southern British Columbia. They are most obvious at large and intermediate map scales. If a more regional view is taken, as in Figs. 2 and 3, the effects of glaciation and Holocene erosion become less obvious. At smaller map scales, long-wavelength landforms, lineaments, and drainage patterns become dominant, which reflect geologic, structural, and tectonic features probably dating further back in time.

The longevity of Eocene or older landscapes 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). Isotopic studies, in particular apatite

(U–Th)/He dating, of rocks in the southern Interior Plateau have the potential to establish the age of geomorphic surfaces and help to resolve some of these issues.

Conclusions

The southern Interior Plateau is an ancient landscape containing relicts of late Mesozoic and Cenozoic landforms, surrounded by more rapidly eroding mountain ranges devoid of most traces of old physiography. Older Late 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. By Middle Eocene time, incision ceased, and fluvial and lacustrine deposition began in the valleys and lowlands. Eocene sedimentary rocks have the lowest position in the landscape and are located near modern base level in large valleys or topographic depressions. They are inset into a higher, older peneplain that dates back at least to the late Mesozoic.

A map of reconstructed paleo-physiography and drainage directions throughout the southern Interior Plateau is presented for Middle to Late Eocene time, ca. 40 Ma. The reconstructed Eocene landscape consists of a northwest-trending swath of highlands, plateaus, plains, and deeply incised valleys, bounded by higher land to the west and east. Base level elevation and relief during Eocene time ranged from 400 to 1300 m.

Regional drainage during the Eocene was broadly northward, in contrast to modern southward drainage. Fluviolacustrine 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. In the Cariboo Plateau, Eocene drainage was northwest along a valley system trending from Quesnel and Shuswap highlands to the Fraser River valley north of Macalister.

Base level increased 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. The preservation of landform remnants of Eocene age and older suggests that glacial erosion is highly variable in space, with only a modest effect at regional scales.

Acknowledgments

Thanks to Bob Anderson for suggesting this contribution. I acknowledge Andrew Okulitch, Stephen Hicock, and Jisuo Jin for reviewing the manuscript. John Clague and Bob Anderson reviewed an early version of the manuscript. Base Mapping and Geomatic Services, Province of British Columbia provided the digital elevation data. This work was supported by a Natural Science and Engineering Research Council of Canada (NSERC) post-graduate scholarship, Natural Resources Canada Earth Sciences Sector supplement, Simon Fraser University graduate fellowships, and Clague's NSERC Operating Grant (217051).

References

Bardoux, M.1985. The Kelowna detachment zone, Okanagan Valley, south-central British Columbia. Geological Survey of Canada, Paper 85-1A, pp. 333–339.

Bevier, M.L. 1983. Regional stratigraphy and age of Chilcotin Group basalts, south-central British Columbia. Canadian Journal of Earth Sciences, **20**: 515–524.

Bostock, H.S. 1941. Ollala, British Columbia. Geological Survey of Canada, Map 628A, scale 1 : 63 360.

Breitsprecher, K. 2002. Volcanic stratigraphy, petrology and tectonic setting of the eastern margin of the Eocene Kamloops Group, south-central British Columbia. Unpublished M.Sc. thesis, Simon Fraser University, Burnaby, B.C.

Brown, R.L., and Journeay, J.M. 1987. Tectonic denudation of the Shuswap metamorphic terrane of southeastern British Columbia. Geology, **15**: 142–146.

Campbell, R.B., and Tipper, H.W. 1971. Geology of the Bonaparte Lake map-area, British Columbia. Geological Survey of Canada, Memoir 363.

Church, B.N. 1973. Geology of the White Lake Basin. British Columbia Department of Mines and Petroleum Resources, Bulletin 61.

Church, B.N. 1975. Geology of the Hat Creek coal basin (92I/13E). British Columbia Ministry of Energy, Mines and Petroleum Resources, Geology in British Columbia. pp. G99–G118.

Church, B.N., and Suesser, U. 1983. Geology and magnetostratigraphy of Miocene basalts of the Okanagan Highlands, British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1981-1, pp. 32–36.

Church, B.N., Jessop, A.M., Bell, R., and Peppitas, A. 1991. Tertiary outlier studies: recent investigations in the Summerland basin, south Okanagan area, British Columbia. British Columbia Geological Survey Branch, Geological Fieldwork 1990, Paper 1991-1, pp. 163–170.

Clague, J.J. (*compiler*). 1989. Quaternary geology of the Canadian Cordillera. *In* Quaternary geology of Canada and Greenland. *Edited by* R.J. Fulton. Geological Survey of Canada, Geology of Canada, no. 1, Chap. 1, (Also Geological Society of America, The Geology of North America, Vol. K-1), pp. 17–96.

Cockfield, W.E. 1961. Geology and mineral deposits of Nicola map-area, British Columbia. Geological Survey of Canada, Memoir 249.

Coleman, M.E., and Parrish, R.R. 1991. Eocene dextral strike-slip and extensional faulting in the Bridge River terrane, southwest British Columbia. Tectonics, **10**: 1222–1238.

Dawson, G.M. 1895. Report on the area of the Kamloops map-sheet. Geological Survey of Canada, Annual Report N.S., 7, pp. 1B–427B.

Drysdale, C.W. 1914. Geology of the Thompson River valley below Kamloops Lake, BC. Geological Survey of Canada, Summary Report 1914, pp. 115–150.

Duffell, S., and McTaggart, K.C. 1952. Ashcroft map-area, British Columbia. Geological Survey of Canada, Memoir 262.

Ewing, T.E. 1981. Regional stratigraphy and structural setting of the Kamloops Group, south-central British Columbia. Canadian Journal of Earth Sciences, **18**: 1464–1477.

Eyles, N., Mullins, H.T., and Hine, A.C. 1991. The seismic stratigraphy of Okanagan Lake, British Columbia: A record of rapid deglaciation in a deep 'fiord-lake' basin. Sedimentary Geology, **73**: 13–41.

Farley, K.A., Rusmore, M.E., and Bogue, S.W. 2001. Post-10 Ma uplift and exhumation of the northern Coast Mountains, British Columbia. Geology, **29**: 99–102.

Fulton, R.J. 1972. Stratigraphy of unconsolidated fill and Quaternary development of north Okanagan Valley. Geological Survey of Canada, Paper 72-8, pp. 9–17.

Fulton, R.J. 1975. Quaternary geology and geomorphology, Nicola–Vernon area, British Columbia. Geological Survey of Canada, Memoir 380.

Graham, P.S.W., and Long, D.G.F. 1979. The Tranquille Beds of the Kamloops Group: a Tertiary (Middle Eocene) coal-bearing sequence in the vicinity of Kamloops Lake, British Columbia. Geological Survey of Canada, Paper 79-1A, pp. 357–360.

Hickson, C.J. 1986. Quaternary volcanism in the Wells Gray – Clearwater area, east central British Columbia. Ph.D. thesis, University of British Columbia, Vancouver, B.C.

Holland, S.S. 1976. Landforms of British Columbia: a physiographic outline. British Columbia Department of Mines and Petroleum Resources, Bulletin 48.

Irving, E., Woodsworth, G.J., Wynne, P.J., and Morrison, A. 1985. Paleomagnetic evidence for displacement from the south of the Coast Plutonic Complex, British Columbia. Canadian Journal of Earth Sciences, **22**: 584–598.

Journeay, J.M., and Monger, J.W.H. 1994. Geology and crustal structure of the southern Coast and Intermontane Belts, southern Canadian Cordillera, British Columbia. Geological Survey of Canada, Open File 2490, map scale 1 : 500 000.

Journeay, J.M., and Monger, J.W.H. 1998. Interactive geoscience library, digital information for the Coast and Intermontane belts of southwestern British Columbia. Vol. 1. Geological Survey of Canada, Open File 3276 (CD-ROM).

Journeay, J.M., and Williams, S.P. 1995. GIS map library: A window on Cordilleran geology. Geological Survey of Canada, Open File 2948 (CD-ROM).

Journeay, J.M., Williams, S.P., and Wheeler, J.O. 2000. Tectonic assemblage map, Kootenay Lake, British Columbia–Alberta–US. Geological Survey of Canada, Open File 2948b, scale 1 : 1 000 000.

Lay, D. 1940. Fraser River Tertiary drainage-history in relation to placer-gold deposits. British Columbia Department of Mines, Bulletin No. 3.

Lay, D. 1941. Fraser River Tertiary drainage-history in relation to placer-gold deposits (part II). British Columbia Department of Mines, Bulletin No. 11.

Long, D.G.F., and Graham, P.S.W. 1993. Sedimentology and coal resources of the early Oligocene Australian Creek Formation, near Quesnel, British Columbia. Geological Survey of Canada, Paper 92-11.

Mahoney, J.B., Vaughn, J., Link, P.K., Riesterer, J.W., Hickson, C.J., and Friedman, R.M. 1999. Late Cretaceous and Paleocene strata along the Intermontane–Methow terrane boundary, southern Chilcotin Plateau, south-central British Columbia. Geological Survey of Canada, Current Research 1999-A, pp. 215–224.

Mathews, W.H. 1981. Early Cenozoic resetting of potassium–argon dates and geothermal history of North Okanagan area, British Columbia. Canadian Journal of Earth Sciences, **18**: 1310–1319.

Mathews, W.H. 1986. Physiography of the Canadian Cordillera. Geological Survey of Canada, Map 1701A, scale 1 : 5 000 000.

Mathews, W.M. 1988. Neogene geology of the Okanagan Highland, British Columbia. Canadian Journal of Earth Sciences, **25**: 725–731.

Mathews, W.H. 1989. Neogene Chilcotin basalts in south-central British Columbia: Geology, ages, and geomorphic history. Canadian Journal of Earth Sciences, **26**: 969–982.

Mathews, W.H. 1991. Physiographic evolution of the Canadian Cordillera. *In* Geology of the Cordilleran Orogen in Canada. *Edited by* H. Gabrielse and C.J. Yorath. Geological Survey of Canada, Geology of Canada, No. 4, (Also Geological Society of America, The Geology of North America, Vol. G-2), pp. 405–418.

Mathews, W.H., and Rouse, G.E. 1984. The Gang Ranch – Big Bar area, south-central British Columbia: Stratigraphy, geochronology, and palynology of the Tertiary beds and their relationship to the Fraser Fault. Canadian Journal of Earth Sciences, **21**: 1132–1144.

Monger, J.W.H. 1969. Hope map-area, west half, British Columbia. Geological Survey of Canada, Paper 69-47.

Monger, J.W.H. 1985. Structural evolution of the southwestern Intermontane Belt, Ashcroft and Hope map areas, British Columbia. Geological Survey of Canada, Paper 85-1A, pp. 349–358.

Monger, J.W.H. 1989. Geology of Hope and Ashcroft map-areas, British Columbia. Geological Survey of Canada, Maps 41-1989, 42-1989 and descriptive notes, scale 1 : 250 000.

Monger, J.W.H., and Journeay, J.M. 1994. Guide to the geology and tectonic evolution of the southern Coast Mountains. Geological Survey of Canada, Open File 2490.

Monger, J.W.H., and Price, R.A. 1979. Geodynamic evolution of the Canadian Cordillera — progress and problems. Canadian Journal of Earth Sciences, **16**: 770–791.

Monger, J.W.H., Price, R.A., and Templeman-Kluit, D.J. 1982. Tectonic accretion and the origin of two major metamorphic and plutonic welts in the Canadian Cordillera, Geology, **10**: 70–75.

Okulitch, A.V. 1979. Lithology, stratigraphy, structure and mineral occurrences of the Thompson–Shuswap–Okanagan area, British Columbia. Geological Survey of Canada, Open File 637, map scale 1 : 250 000.

Okulitch, A.V. 1989. Revised stratigraphy and structure in the Thompson-Shuswap-Okanagan map area, southern British Columbia. Geological Survey of Canada, Paper 89-1E, pp. 51–60.

Panteleyev, A., and Hancock, K.D. 1988. Quesnel Mineral Belt: summary of the geology of the Beaver Creek – Horsefly River map area. British Columbia Ministry of Energy Mines and Petroleum Resources, Geological Fieldwork, Paper 1989-1, pp. 159–166.

Panteleyev, A., Bailey, D.G., Bloodgood, M.A., and Hancock, K.D. 1996. Geology and mineral deposits of the Quesnel River-Horsefly map area, central Quesnel Trough, British Columbia. British Columbia Geological Survey Branch, Bulletin 97.

Parrish, R.R. 1983. Cenozoic thermal evolution and tectonics of the Coast Mountains of British Columbia, 1: fission track dating, apparent uplift rates, and patterns of uplift. Tectonics, **2**: 601–631.

Preto, V.A. 1979. Geology of the Nicola Group between Merritt and Princeton. British Columbia Ministry of Energy, Mines and Petroleum Resources, Bulletin 69.

Read, P.B. 1988*a*. Miocene stratigraphy and industrial minerals, Bonaparte to Deadman River area, southern British Columbia. *In* Geological fieldwork 1988. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1989-1, pp. 515–518.

Read, P.B. 1988*b*. Tertiary stratigraphy and industrial minerals, Cache Creek (92I/14), British Columbia. British Columbia Ministry of Energy and Mines, Geological Survey Branch, Open File 1988-30, map scale 1 : 50 000.

Read, P.B. 2000. Geology and industrial minerals of the Tertiary basins, south-central British Columbia. British Columbia Ministry of Energy and Mines, Geological Survey Branch, GeoFile 2000-3.

Reiners, P.W., Ehlers, T.A., Garver, J.I., Gran Mitchell, S., Montgomery, D.R., Vance, J.A., and Nicolescu, S. 2002. Late Miocene exhumation and uplift of the Washington Cascade Range. Geology, **30**: 767–770.

Rice, H.M.A. 1947. Geology and mineral deposits of the Princeton map-area, British Columbia. Geological Survey of Canada, Memoir 243.

Riesterer, J.W., Mahoney, J.B., and Link, K. 2001. The conglomerate of Churn Creek: Late Cretaceous basin evolution along the Insular–Intermontane superterrane boundary, southern British Columbia. Canadian Journal of Earth Sciences, **38**: 59–73.

Rouse, G.E., and Mathews, W.H. 1979. Tertiary geology and palynology of the Quesnel area, British Columbia. Bulletin of Canadian Petroleum Geology, **27**: 418–445.

Schiarizza, P., and Preto, V.A. 1987. Geology of the Adams Plateau – Clearwater – Vavenby area. British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Survey Branch, Paper 1987-2.

Schiarizza, P., Gaba, R.G., Glover, J.K., Garver, J.I., and Umhoefer, P.J. 1997. Geology and mineral occurrences of the Taseko– Bridge River area. British Columbia Geological Survey Branch, Bulletin 100.

Souther, J.G. 1991. Volcanic regimes. *In* Geology of the Cordilleran Orogen in Canada. *Edited by* H. Gabrielse and C.J. Yorath. Geological Survey of Canada, Geology of Canada, No. 4, Chap. 14, (Also Geological Society of America, The Geology of North America, Vol. G-2), pp. 457–490.

Templeman-Kluit, D., and Parkinson, D. 1986. Extension across the Eocene Okanagan crustal shear in southern British Columbia. Geology, **14**: 318–321.

Thompson, R.I., and Daughtry, K.L. 1994. A new regional mapping project in Vernon map area, British Columbia. Geological Survey of Canada, Current Research 1994-A, pp. 117–122.

Thorkelson, D.J. 1989. Eocene sedimentation and volcanism in the Fig Lake Graben, southwestern British Columbia. Canadian Journal of Earth Sciences, **26**: 1368–1373.

Tipper, H.W. 1971. Glacial geomorphology and Pleistocene history of central British Columbia. Geological Survey of Canada, Bulletin 196.

Tribe, S. 2002. Geomorphic evidence for Tertiary drainage networks in the southern Coast Mountains, British Columbia. Geological Survey of Canada, Current Research 2002-A13, 8 p.

Tribe, S. 2003. Physiography and Tertiary base levels in the southern Interior Plateau and adjacent areas, southwestern British Columbia. Geological Survey of Canada, Current Research 2003-A2, 11 p.

Tribe, S. 2004. Cenozoic drainage history of southern Interior Plateau, British Columbia. Unpublished Ph.D. thesis, Simon Fraser University, Burnaby, B.C.

Uglow, W.L. 1923. Cetaceous age and early Eocene uplift of a peneplain in southern British Columbia. Geological Society of America Bulletin, **34**: 561–572.

Umhoefer, P.J. 1987. Northward translation of “Baja British Columbia” along the Late Cretaceous to Paleocene margin of western North America. Tectonics, **15**: 545–565.

Vanderburgh, S., and Roberts, M.C. 1996. Depositional systems and seismic stratigraphy of a Quaternary basin: North Okanagan Valley, British Columbia. Canadian Journal of Earth Sciences, **33**: 917–927.

Wilcox, R.E, Harding, T.P., and Seely, D.R. 1973. Basic wrench tectonics. American Association of Petroleum Geologists Bulletin, **57**: 74–96.

Wilson, M.V.H. 1977. Paleoecology of Eocene lacustrine varves at Horsefly, British Columbia. Canadian Journal of Earth Sciences, **14**: 953–962.

Wilson, M.V.H. 1982. A new species of the fish Amia from the middle Eocene of British Columbia. Palaeontology, **25**:413–424.