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Geomorphic evidence for Tertiary drainage networks in the southern Coast Mountains, British Columbia

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Abstract: Tertiary drainage networks are reconstructed by mapping drainage anomalies and valley trends on shaded-relief maps of the southern Coast Mountains (NTS 92 G, 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 late Miocene–Pliocene regional uplift.

Résumé : Les réseaux d'écoulement du Tertiaire de la partie sud de la chaîne Côtière (SNRC 92G, H, I, J) ont été reconstitués en reportant sur des cartes à relief ombré les anomalies du système d'écoulement des eaux et les axes des vallées. Des relations structurales et géologiques permettent d'établir des limites d'âge pour la formation des vallées. À proximité de Gold Bridge, les rivières Bridge et Seton primitives s'écoulaient vers le nord-est, entre le Crétacé terminal et l'Éocène. Des mouvements de coulissage le long des failles de Yalakom et du Fraser ont détourné les eaux des rivières vers le sud-ouest au cours de l'Éocène. La vallée de la rivière Lillooet recoupe la trace des rivières Bridge et Seton primitives et les eaux du cours supérieur de celles-ci y ont été canalisées. Des observations géomorphologiques indiquent que l'écoulement des eaux du fleuve Fraser primitif ne s'est effectué vers le sud le long de la trace de la faille du même nom qu'un certain temps après le jeu par coulissage de cette faille à l'Éocène. Un réseau fluvial dendritique s'est formé à la grandeur de la région au Miocène et les cours d'eau qui le constituent se sont enfoncés lors du soulèvement régional au Miocène tardif et au Pliocène.

INTRODUCTION

Valleys in the Coast Mountains physiographic province (Holland, 1976) of British Columbia have been shaped by river erosion, glaciation, mass wasting, and tectonics throughout the Quaternary, 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.

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, and allow landforms to be mapped with the detail of stereo airphoto interpretation (e.g. 1:50 000 scale) at map 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, and is part of ongoing doctoral research into Tertiary drainage networks in central and southern British Columbia.

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 consulted.

GEOLOGY AND STRUCTURE OF THE STUDY AREA

Bedrock geology in the northeast part of the study area between Gold Bridge and Lillooet is dominated by Paleozoic and Mesozoic fault-bounded northwest-trending terranes (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 1 shows the distribution of mapped Tertiary and Quaternary rocks. A few small Tertiary outcrops south of Hope and east of the Fraser River are omitted for the 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. 2). The Ashlu Creek, Fire Creek, and Owl Creek faults are thrust faults thought to have been active in late Cretaceous time (Monger and Journeay, 1994). The Harrison Lake Fault is a dextral strike-slip fault dated at 93 Ma (Monger and Journeay, 1994). The Downton Creek Fault accommodated both southwest-directed thrusting and dextral strike-slip movement (Monger and Journeay, 1994). It is estimated to have been active from 85 Ma 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 study area and consists of northwest-striking early Tertiary to Eocene strike-slip faults and some normal faults (Fig. 2). The Yalakom strike-slip fault accumulated 100–170 km of right-lateral offset from 57 Ma to 45 Ma (Umhoefer and Schiarizza, 1996). The Fraser Fault accommodated 80–120 km of right-lateral strike-slip displacement between 47 Ma and 35 Ma (Monger and Journeay, 1994). The Mission Ridge Fault is a low-angle, northeast-dipping normal fault that was active 45–44 Ma (Umhoefer and Schiarizza, 1996). The southwest-dipping Marshall Creek Fault is estimated to have had 3.5 km of normal displacement (Coleman and Parrish, 1991) and at least 10 km of dextral strike-slip (Monger and Journeay, 1994) sometime between 44 Ma and 34 Ma (Garver et al., 1994; Umhoefer and Schiarizza, 1996).

GEOMORPHIC EVIDENCE FOR RELICT VALLEYS

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

Oblique to the southeast-trending valleys, but just as large, are a set of prominent northeast- and east-trending valleys containing Bridge River and Seton River. These valleys appear to be contiguous across the 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 2–3 km, and relief of more than 2100 m. Near the town of Gold Bridge, the Bridge River valley and the large tributary valley drained by Hurley River both attain widths of 5 km or more. In the region between the 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. 3). Examples include Anderson Lake (290 m a.s.l.) and Seton Lake (243 m a.s.l.) within the Seton River valley, Gun Lake (940 m a.s.l.) in the Bridge River valley, Duffey Lake (1120 m a.s.l.) in the Cayoosh Creek valley, and Nahatlatch Lake (300 m a.s.l.) along Nahatlatch River. Carpenter and Downton lakes, in the Bridge River valley, are man-made lakes. Prior to damming, the Bridge River valley contained a meandering underfit stream.

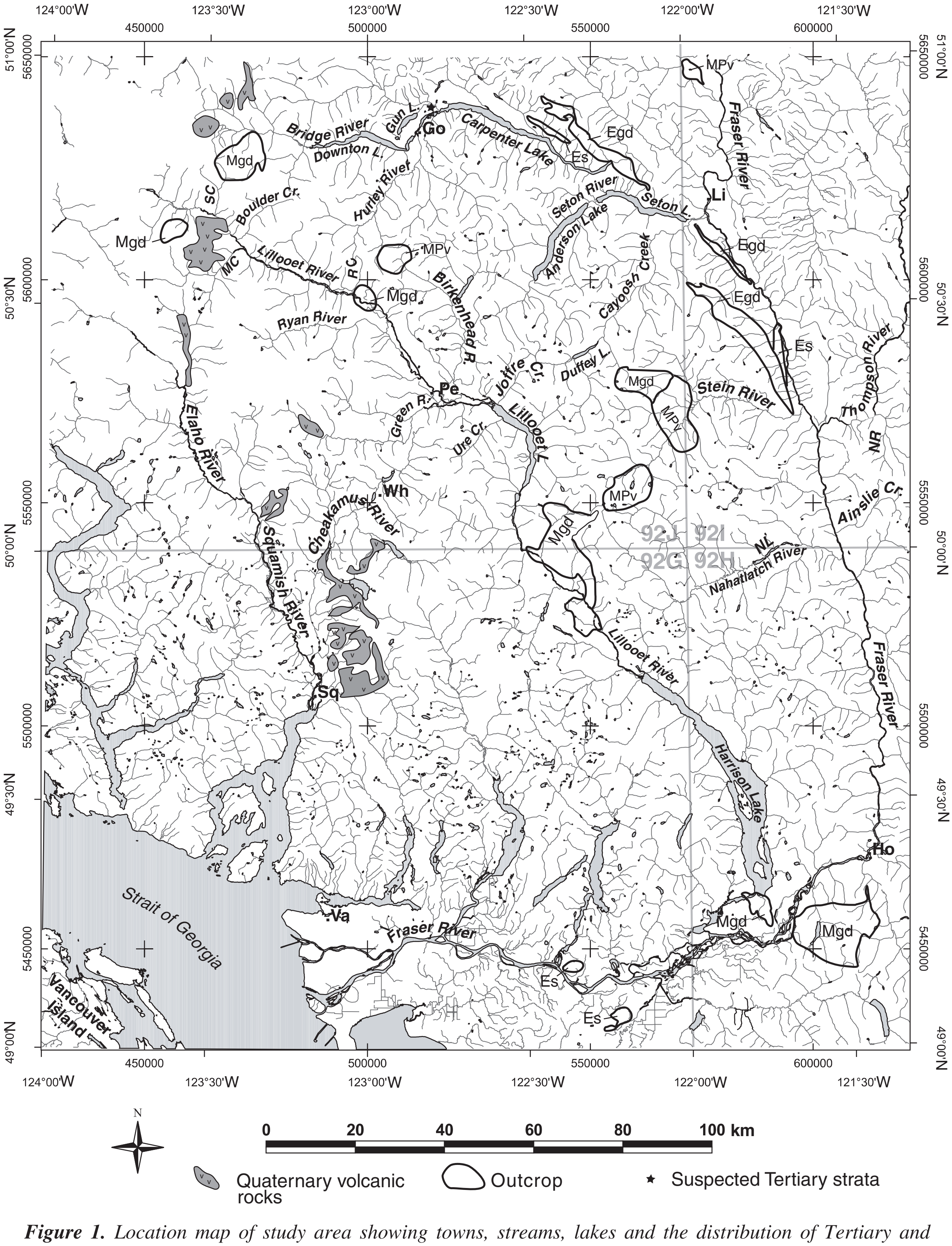

Figure 1. Location map of study area showing towns, streams, lakes and the distribution of Tertiary and Quaternary rocks. Towns are: Va, Vancouver; Sq, Squamish; Wh, Whistler; Pe, Pemberton; Go, Gold Bridge; Li, Lillooet; Ho, Hope. Abbreviated streams and lake are: SC, Salal Creek; MC, Meager Creek; RC, Railroad Creek; NR, Nicoamen River; NL, Nahatlatch Lake. Rock abbreviations are: Egd, Eocene granodiorite; Es, Eocene sedimentary rocks; Mgd, Miocene granodiorite; MPv, Miocene–Pliocene volcanic rocks. Areas of sparse stream density in the northwest are icefields. Digital stream, lake, and geology data from Journeay and Monger (1998).

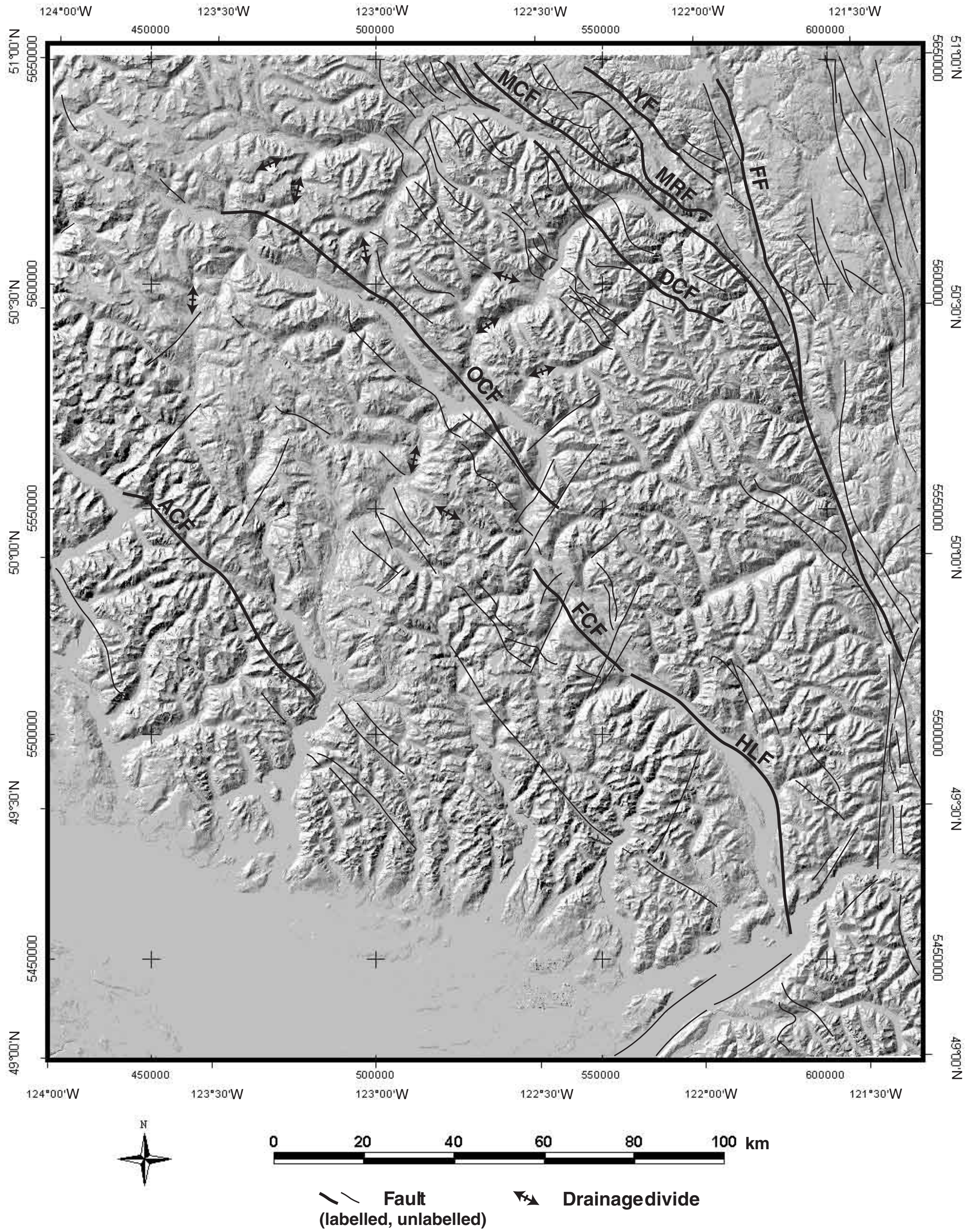

Figure 2. Shaded-relief map of study area illuminated from the northwest. Labelled faults are shown with bold lines: FF, Fraser Fault; YF, Yalakom Fault; MRF, Mission Ridge Fault; MCF, Marshall Creek Fault; DCF, Downton Creek Fault; OCF, Owl Creek Fault; FCF, Fire Creek Fault; HLF, Harrison Lake Fault; ACF, Ashlu Creek Fault. Fault data from Journeay and Monger (1998).

Figure 3.

View westward along Seton Lake from Highway 99 approximately 7 km west of Lillooet. Train in lower right for scale.

Many of the northeast-trending valleys contain mid-valley drainage divides from which underfit streams flow southwestward into the Lillooet River (Fig. 2). Salal Creek and Boulder Creek flow southwesterly from drainage divides in the Bridge River valley; Railroad Creek flows southwesterly from a divide in the Hurley River valley; Joffre Creek flows from a divide in the Cayoosh Creek valley; and streams tributary to the Birkenhead River flow from divides along the Seton River valley. Mid-valley drainage divides are also present west of the Lillooet River. All are located within 30 km of the 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 the Stein River between Harrison Lake and the Fraser River (Fig. 2). The valleys are relatively short and curvilinear in plan, with depths of 0.5–1.2 km and valley bottom widths of 0.5–1 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 1 closely follows the dendritic valley pattern.

GEOLOGICAL CONSTRAINTS ON VALLEY AGE

Bounds 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 the Bridge River valley are Eocene fluvial sediments located north of Carpenter Lake, and suspected Tertiary fluvial deposits located near Gold Bridge (star on Fig. 1). The Eocene fluvial sediments occur at an elevation of 840 m a.s.l. and are in depositional contact on Paleozoic bedrock (P. Schiarizza, pers. comm., 2001). The suspected Tertiary strata occur at an elevation of 685 m a.s.l. and consist of silica-cemented fluvial gravel and sand deposited by northeast-flowing streams. The sand contains fossil willow leaves. Samples are currently being analyzed for microfossils to obtain an age. Although Seton River valley contains no mapped valley deposits older than Quaternary, it is interpreted to have the same age bounds as the Bridge River valley by virtue of its proximity and similarity of size and trend. The minimum age of the 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, the 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 the Marshall Creek, Mission Ridge, and Yalakom faults. The valley then turns again to the northeast and crosses the trace of the Marshall Creek Fault. Downstream from this point, the Bridge River flows in a narrow, rock-walled canyon 250–400 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 the Yalakom River, then it flows along the trace of the Yalakom Fault to the Fraser River. Similarly, the trend of the Seton River valley changes from northeast to southeast as it approaches the Marshall Creek and Mission Ridge faults. Upon crossing the faults, it then narrows to a gorge less than 1 km wide, which is graded to the level of the 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 the Eocene.

For other large northeast-trending valleys there are fewer lithological controls on age. 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. This suggests 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 as the 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 the Thompson River and Ainslie Creek–Nicoamen River valleys (Fig. 2). If this interpretation is correct, then 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 the Stein River provide a minimum age but it is not known if these rocks are valley-filling deposits.

A maximum Paleocene age for the 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 the Bridge and Seton river valleys; however, the Lillooet River valley exposes Miocene granodiorite, which suggests a younger maximum age were it not for the great size of the valley. The granodiorite, exposed 20 km south of Lillooet Lake, requires a minimum of 2000 m of incision after Miocene time. A minimum Quaternary age for the 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), located 20 km southwest of Hope (Fig. 1). 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 Recent 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 late Pleistocene.

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 geological 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.

At the east end of Carpenter and Seton lakes, and within the Lillooet and Stein river valleys, Eocene and Miocene granodiorite bodies are incised. This seems to contradict the inferred latest Cretaceous to Eocene maximum ages of the valleys were it not that dating studies show parts of the Coast Mountains experienced significant regional uplift during late Miocene to Pliocene time. Apatite and zircon fission-track studies in the southern Coast Mountains by Parrish (1983) revealed a period of rapid apparent uplift from about 45 Ma to 35 Ma, followed by very low uplift rates from 30 Ma to 10 Ma, and a final period of rapid apparent uplift of 2–3 km from about 10 Ma to 2 Ma. Apatite (U-Th)/He ages in the northern Coast Mountains revealed 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 Ma to 4 Ma; followed by a period of rapid exhumation on the order of 1 km starting 4 Ma ago (Farley et al., 2001). Given the well documented episode of late Miocene–Pliocene regional uplift, incision through Eocene and Miocene rocks must have occurred late 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 4 presents inferred drainage patterns 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 age constraints.

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. 4A). 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 the Lillooet River valley and likely drained an ancestral Coast Mountain Range in the southwest.

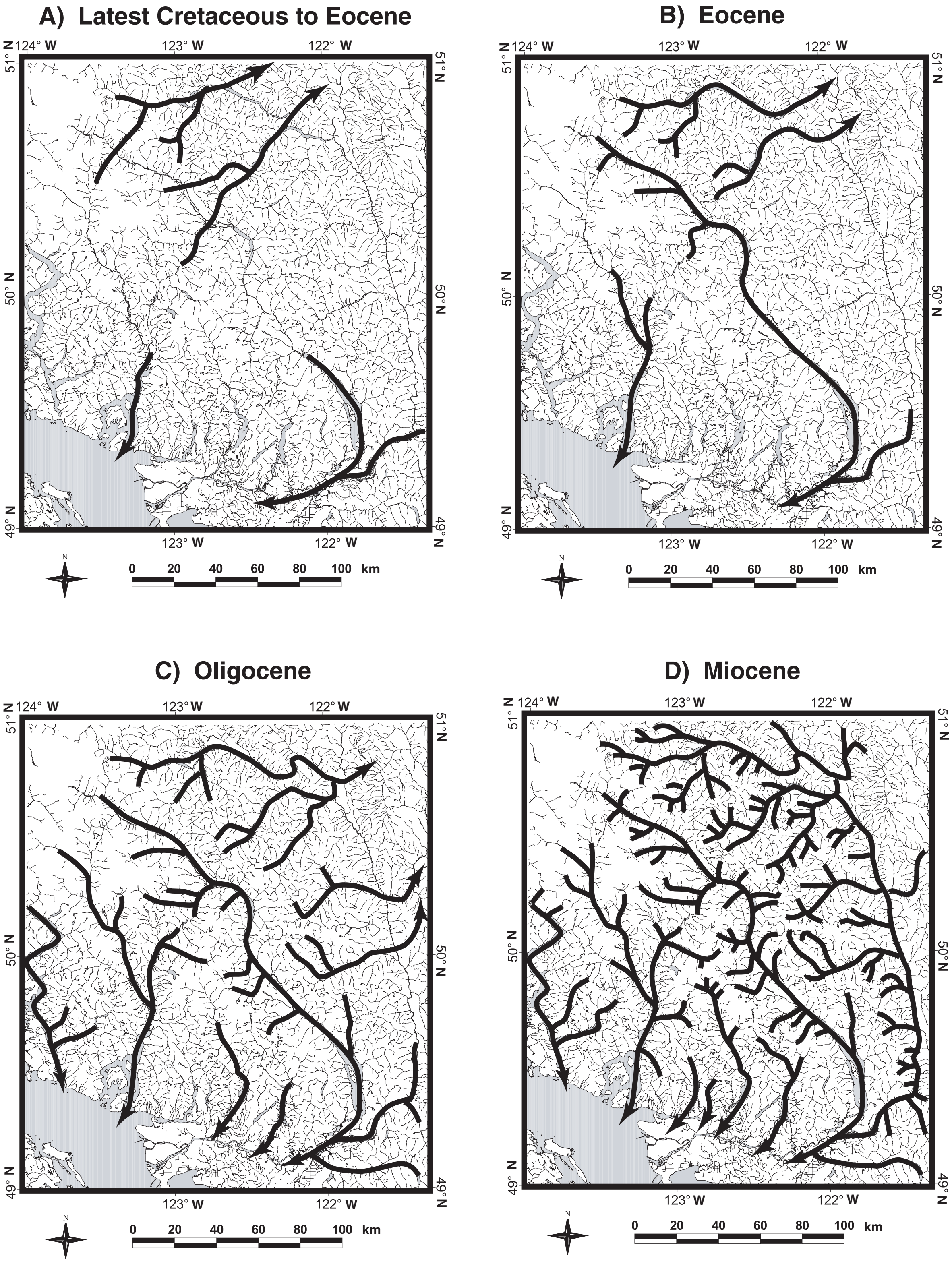

Figure 4. Reconstructed drainage networks during: ***A****) latest Cretaceous to Eocene,* ***B****) Eocene,* ***C****) Oligocene, and* ***D****) Miocene.*

The second panel represents drainage patterns during Eocene time when the Yalakom and Fraser faults were active (Fig. 4B). Fault-induced relief forced the formerly northeast-flowing ancestral rivers towards the east and southeast along the trace of the faults. Eventually, the rivers were able to cross the faults and resume their northeasterly direction. The ancestral Lillooet River valley captured the headwaters of the ancestral Bridge and Seton rivers.

The third panel depicts drainage patterns during the Oligocene after the cessation of strike-slip faulting (Fig. 4C). The valleys of Cayoosh Creek, Stein River, and Nahatlatch River, were carved by ancestral rivers flowing toward the northeast. The last two rivers 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 the Miocene prior to the onset of rapid uplift in the late Miocene (Fig. 4D). Streams elaborated and elongated their networks. Ancestral Fraser River probably flowed southward along the trace of the Fraser Fault. Rapid uplift in the late Miocene–Pliocene 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 are dated by lithological and structural controls.

The oldest valleys preserved are those of the ancestral Bridge and Seton rivers that flowed northeasterly sometime between the latest Cretaceous and Eocene. Their progressive narrowing and change in trend to the southeast as they approach Eocene strike-slip faults near Lillooet, indicate the 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 the Fraser and Yalakom faults.

The Lillooet River valley crosscut the ancestral Bridge and Seton rivers and captured their headwaters. The 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 the Oligocene and Miocene, 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 in the Miocene.

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

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