Eocene sedimentation and volcanism in the Fig Lake Graben, southwestern British Columbia

DEREK J. THORKELSON
Ottawa–Carleton Geoscience Centre, Department of Earth Sciences, Carleton University, Ottawa, Ont., Canada K1S 5B6

Received May 30, 1988
Revision accepted December 15, 1988

The Fig Lake Graben is a narrow, complex Eocene basin that developed along part of the Coldwater fault system in southwestern British Columbia. Its origin as a pull-apart basin is probably related to dextral wrench faulting along the Fraser Fault and low-angle normal faulting of the Okanagan shear zone. Within the graben are Kamloops Group volcanic and sedimentary rocks, the thickness of which implies that one fault block has been downthrown at least 4.5 km. Geochemical interpretation of previously published analyses of Kamloops Group volcanic rocks indicates that magma production was genetically related to both extension and subduction.

Le graben du Fig Lake est un bassin complexe étroit, d'âge éocène, développé le long d'un segment du système de failles de Coldwater, dans le sud-ouest de la Colombie-Britannique. L'origine du graben, en tant que bassin d'extension, est probablement reliée à un décrochement dextre le long de la faille du Fraser et au mouvement d'une faille normale subhorizontale dans la zone de cisaillement d'Okanagan. Les roches volcaniques et sédimentaires du Groupe de Kamloops gisent dans le graben, et leur épaisseur est telle qu'un bloc de faille a dû être affaissé d'au moins 4,5 km. L'interprétation géochimique des analyses déjà publiées des roches volcaniques du Groupe de Kamloops révèle que le magma produit était relié génétiquement aux stades d'extension et de subduction.

[Traduit par la revue]

Can. J. Earth Sci. **26**, 1368–1373 (1989)

Introduction

In the last few years, Eocene extension of southern British Columbia has become an important theme in the literature (e.g., Monger 1985; Bardoux 1985; Parrish *et al.* 1985; Tempelman-Kluit and Parkinson 1986; Carr *et al.* 1987; Brown and Journeay 1987; B. J. Johnson 1988, 1989; Parrish *et al.* 1988). Key papers that preceded this explosion of information were written by Ewing (1979*a*, 1979*b*, 1980, 1981*a*, 1981*b*, 1982), who concurred with Price (1979, 1981) in relating paired dextral offsets across the Fraser and Northern Rocky Mountain Trench fault systems to widespread horst and graben development east of the Fraser River. Despite Ewing's comprehensive descriptions of volcanism and sedimentation in Eocene pull-apart basins and his insightful depiction of British Columbian core complexes, his contributions were not acknowledged by some of the later workers.

In a discussion of the Fig Lake Graben, this paper utilizes the Eocene tectonic framework developed in British Columbia by Ewing, enhanced by Monger and McMillan (1984) and Monger (1985), and recognized in Washington by S. Y. Johnson (1985, and earlier works) and Taylor *et al.* (1988). In addition, minor and trace elements of Ewing's (1981*b*) chemical analyses are plotted on discriminant diagrams in order to clarify the tectonic affinity of synextensional Kamloops Group volcanism.

Structural framework

Coldwater fault system

The Coldwater fault system is a prominent structure of the southern Intermontane Belt that lies between two much larger features, the Fraser Fault and the Okanagan shear zone (Fig. 1). The Fraser Fault is responsible for roughly 90 km of dextral strike slip (Mathews and Rouse 1984; Kleinspehn 1985; Monger 1985), whereas the Okanagan Shear, a low-angle normal fault (Bardoux 1985), accounts for up to 90 km of west-northwest extension (Tempelman-Kluit and Parkinson 1986). The Coldwater fault system is part of an intervening network of Eocene strike-slip and normal faults that apparently formed in response to transtensional stress (Monger 1985) between the larger structures. At its northern end, near Kamloops, it intersects the northwest-trending Cherry Creek Fault. Between that junction and Merritt it forms the western boundary of the Nicola Horst, a complex of upper Paleozoic to Paleocene volcanic, plutonic, and metamorphic rocks showing Late Cretaceous to Paleogene K–Ar reset or quenching ages (Preto *et al.* 1979; Ewing 1981*a*; Monger and McMillan 1984; Monger 1985). Farther south, that trend of deeper level rocks exposed to the east of the fault system continues to Kingsvale, where the sense of displacement becomes reversed. The fault system extends southward for at least another 20 km, where, according to mapping by Rice (1947) and Monger (1985), it dies out on the western flank of Mount Thynne; displacement is apparently transferred to northwesterly-trending structures to the east. A strong lineament exists south of its supposed terminus, however, suggesting that it may continue in a more southerly direction down Lawless Creek toward the east side of the Tulameen zoned ultramafite (Fig. 1).

Fig Lake Graben

The Fig Lake Graben comprises a set of narrow, downdropped fault slivers within a complex, north-trending segment of the Coldwater fault system, near Kingsvale (Fig. 2). The graben is bounded on the east and west by two major fault splays, the Kingsvale Fault and the Fig Fault, respectively. The graben's southern limit is defined by the intersection of those splays, near Fig Lake. To the north, the graben ends where the Coldwater fault system abruptly changes direction and becomes a single, northeasterly-trending strand, the Coldwater Fault. To the west, the graben intersects the northwesterly-trending Midday Fault, which serves as a master to an array of minor faults to the south. Those minor faults offset stratigraphy within the mid-Cretaceous Spences Bridge Group and also its unconformity with underlying Triassic

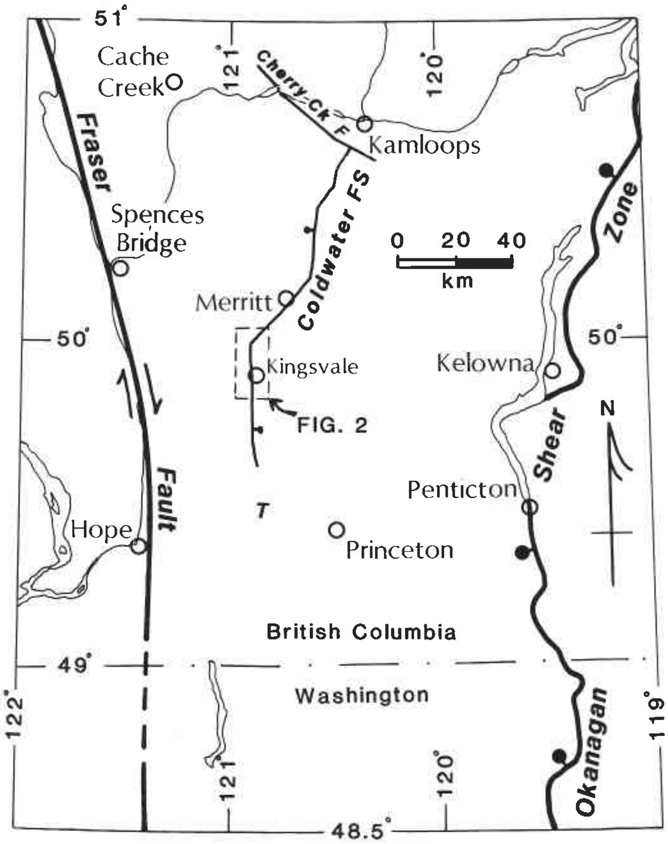

FIG. 1. Location map of the Fig Lake Graben (Fig. 2), showing major Eocene structures: the dextral strike-slip Fraser Fault; the low-angle, normal Okanagan shear zone; the Cherry Creek Fault; and the Coldwater fault system (after Monger 1985 and Carr *et al.* 1987). T, Tulameen zoned ultramafite.

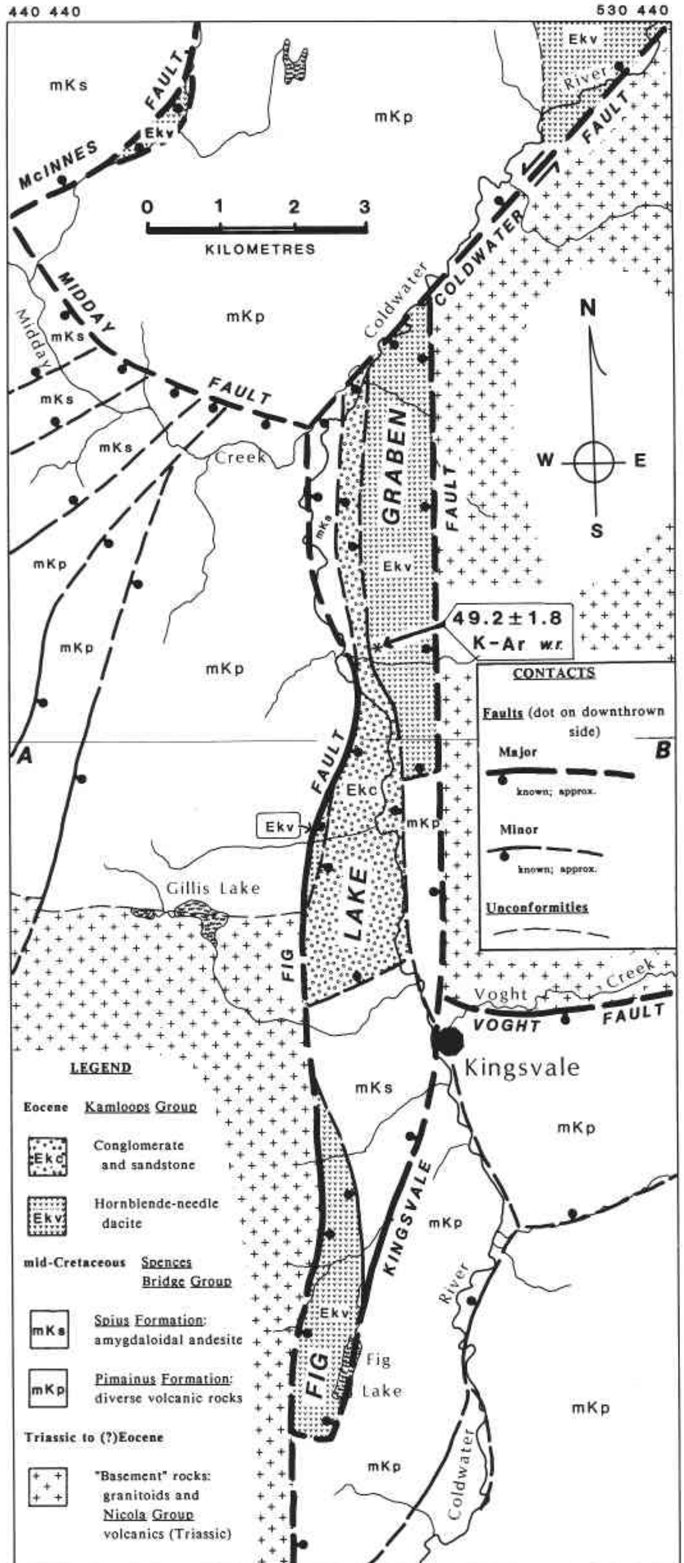

FIG. 2. Map of the Fig Lake Graben, showing major structures and geological units. Area lies in northwest corner of NTS 1 : 50 000 map sheet 92 H/15 and southwest corner of sheet 92 I/2. Corners of diagram are defined by UTM grid coordinates (easting, northing).

volcano-plutonic "basement" rocks of the Nicola Arc. The Midday Fault also connects with the McInnes Fault, whose splays bound a small graben of Eocene Kamloops Group hornblende dacite prophyry. To the east, near Kingsvale, the Fig Lake Graben is met by the Voght Fault, which separates basement rocks to the north, including the Triassic Coldwater Stock of Preto *et al.* (1979), from Spences Bridge Group rocks to the south. It is this fault that coincides with the reversal in sense of displacement across the Coldwater fault system; south of Kingsvale, offset is east-side down.

Deposits within the Fig Lake Graben

Exposed in the Fig Lake Graben are sections of both Pimainus and Spius formations of the Spences Bridge Group (nomenclature to be formalized in Thorkelson and Rouse 1989) and Kamloops Group volcanic and sedimentary rocks. Details regarding the Cretaceous strata were given by Rice (1947) and Thorkelson (1985, 1986). The Kamloops Group volcanic rocks, in places maroon, are hornblende ± plagioclase ± biotite phyric lavas and rare pyroclastic deposits of probable dacitic composition. The needlelike basaltic hornblende phenocrysts show effects of reaction with the melt by peripheral rimming or complete pseudomorphing by opaque oxides. The groundmass consists mainly of tiny flow-aligned plagioclase laths and equant grains of magnetite. This lithotype is typical of Eocene lavas throughout the Merritt–Kingsvale–Spences Bridge region (J. W. H. Monger, personal communication, 1984) and is common to the Kamloops Group in general (Ewing 1981*b*). A 49.2 ± 1.8 Ma K–Ar whole-rock date supports its Middle Eocene age (Table 1; Fig. 2). The chemo-tectonic affinity of coeval mafic flows and intrusions near Kamloops is discussed later.

TABLE 1. Data for K–Ar age determination

Rock type	Hornblende dacite
Material dated	Whole rock
Latitude	49°57′18″N
Longitude	120°55′23″W
UTM coordinates	10U FL 490 355
K (wt.%)	2.02
Radiogenic ^{40}Ar ($\times 10^6$ cm^3/g)	3.918
Percentage of total ^{40}Ar	68.7
Model age (Ma)	49.2 ± 1.8 (1σ)

NOTES: Analyses by K. Scott (K) and J. Harakal (Ar), Department of Geological Sciences, The University of British Columbia. K was determined in duplicate by atomic absorption using a Techtron AA4 spectrophotometer; Ar, by isotope dilution using an AE1 MS-10 mass spectrometer and high-purity ^{38}Ar spike. Constants used: $K_e = 0.581 \times 10^{-10}$ a^{-1}; $^{40}K/K = 0.01167$ at.%. Uncertainty reported is for one standard deviation.

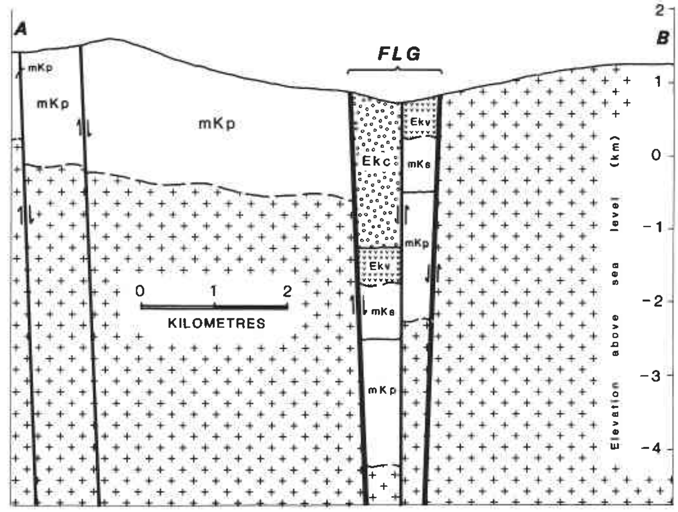

FIG. 3. Schematic east–west cross section through the Fig Lake Graben, 4 km north of Kingsvale (section line A–B on Fig. 2). Formation thicknesses are approximate; fault dips are speculative. No vertical exaggeration. FLG, Fig Lake Graben; other symbols as in Fig. 2.

The downfaulted Kamloops Group sedimentary section (Fig. 3) comprises poorly indurated, well-bedded, polymictic conglomerate and sandstone (Fig. 4). Rounded to subrounded cobbles and pebbles of mainly volcanic and plutonic rocks are largely supported by a moderately friable sandstone matrix. Clast types include hornblende-needle dacite of identical lithology to nearby Eocene lavas. The presence of such clasts and the absence of lava flows within the sequence suggest that this conglomeratic unit may be entirely younger than the volcanics. Imbrication of pebbles in the northern part of the section (UTM 487 357) implies a northerly paleocurrent. This unit extends for at least 4 km in an apparently unbroken section. Bedding dips vary from 25° to 40° to the northeast or northwest, implying a total thickness in excess of 2 km.

This conglomeratic succession is interpreted as a braided-stream deposit that formed in response to, and contemporaneously with, downfaulting. In this way, the graben was filled as it formed. It is possible that this succession was deposited in the same fluviolacustrine waterway as the conglomerate, sandstone, shale, and coal of the Coldwater Formation (Kamloops Group) at Merritt (Cockfield 1948). Block rotation by continued deformation tilted the Fig conglomerates northward. Strata in the fault sliver immediately to the south of the conglomerates dip gently to the southeast, implying that fault blocks within the graben moved, at least in part, independently. The hornblende-phyric lavas may also have been deposited within the developing Fig Lake Graben, in the manner described by Ewing (1981*a*), during an earlier stage of extension. Support for that hypothesis is given by north-trending felsic and mafic dykes, some of which are hornblende bearing, that intrude Triassic and Cretaceous rocks south of Kingsvale. These dykes are especially abundant on the summit of Mount Thynne, about 20 km south of Kingsvale, where they strike 170°; their proximity and parallelism to the Coldwater Fault suggest that volcanism may have been localized in this zone of extension.

Displacement type and magnitude

The amount of vertical displacement across the Fig Lake Graben is probably the greatest north of the Voght Fault. There, volcano-plutonic "basement" rocks east of the Kingsvale Fault either are devoid of cover or, as mapped by Rice (1947), are capped by thin outliers of the Spences Bridge Group. Across the graben, west of the Fig Fault, at least 2.5 km of Spences Bridge Group lavas unconformably overlies similar basement units (Thorkelson 1985), implying at least 2.5 km west-side-down displacement. Fault blocks within the graben were further downdropped (Fig. 3). The fault slice hosting the conglomeratic succession (Fig. 4), judging by deposit thickness, was additionally offset at least 2 km, making total vertical displacement at least 4.5 km relative to basement to the east.

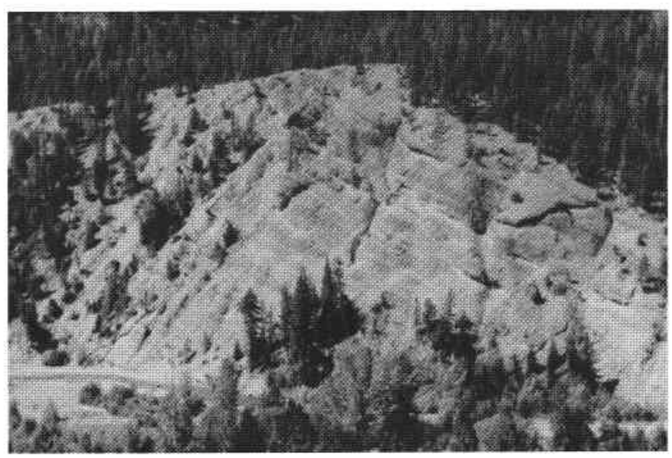

FIG. 4. Cliff of Kamloops Group conglomerate and sandstone above the western bank of the Coldwater River, 4 km north of Kingsvale.

The Fig Lake Graben could have developed as a pull-apart basin in response to a component of strike-slip displacement along the Coldwater Fault, the northeast-trending segment of the Coldwater fault system extending from the northern end of the graben through Merritt (Figs. 1, 2). Sinistral offset along that segment is likely to have produced tension within the north-trending segment near Kingsvale (Fig. 2), resulting in crustal extension and downfaulting. The exact amount of sinistral offset cannot be calculated because dip angles of the faults and magnitude of downthrow for all blocks in the graben are not known. Because the graben faults are probably steep, however, left-lateral displacement is not likely to exceed a few hundred metres.

Many extensional basins related to strike-slip faulting have been reported throughout the northern Cordillera (Long 1981; S. Y. Johnson 1985; Eisbacher 1985; Taylor *et al.* 1988). Nearby pull-apart basins of Eocene age include those at Hat Creek (Church 1975), Tranquille (Ewing 1981*a*), and Princeton (McMechan 1983), which exhibit generally east–west dilation apparently caused by throughgoing dextral strike-slip faults (Ewing 1981*a*). The contemporaneous Fig Lake Graben shares that direction of extension but appears to have been produced by sinistral rather than dextral offset. Although speculative, that sense of displacement is consistent with the empirical and experimental studies of brittle wrench-fault strain by Wilcox *et al.* (1973). When their model is applied to north-northwesterly-trending dextral wrench offset along the Fraser Fault (Monger 1985), the orientation of the northeasterly-trending segment of the Coldwater structure lies between the predicted azimuth for normal faults and that of sinistral, antithetic strike-slip faults. Such an orientation is consistent with oblique faulting of combined normal and left-lateral offset. Further analysis of the more northerly and southerly portions of the Coldwater fault system and of related Eocene structures is necessary to test this hypothesis of graben development against the regional pattern of strain.

Tectonic affinity of Kamloops Group volcanism

The Kamloops Group volcanics, despite an intimate association with transtensional graben formation, were interpreted by Ewing (1981*b*) and Smith (1986) as a high-alkali, calc-alkaline, arc-generated succession. That conclusion, based largely on major-element trends and normative mineralogy, can be tested by analysis of trace-element data.

Ewing's (1981*b*) analyses, from eruptive and intrusive rocks near Kamloops, included several trace elements that are valuable indicators of tectonic affinity. Of his 20 samples, 14 have SiO_2 contents between 47 and 58% and are sufficiently mafic to use on basalt discriminant diagrams. Eleven of those were analyzed for trace elements; four of them have $Cr > 170$ ppm. It is these primitive, high-Cr samples that are probably least contaminated and fractionated and should therefore be most indicative of primary geochemistry. Hornblende-bearing lavas of the Fig Lake Graben were not analyzed.

On the Pearce (1982) Ti versus Zr diagram (Fig. 5), seven of the 11 samples, including three of the four high-Cr samples, plot in the arc field. The remaining four plot in the within-plate field, and none lies in the zone of mid-ocean-ridge-basalt (MORB) overlap. In Fig. 6, which is a diagram of V versus Ti (Shervais 1982), most of the samples, including two of the high-Cr specimens, plot in the MORB field. Indeed, the other two high-Cr samples lie just inside the arc envelope in the shared MORB–arc field. All specimens have $Ti/V > 27$, indicative of moderately low source-rock oxygen fugacity. On the $MnO - TiO_2 - P_2O_5$ ternary diagram (Fig. 7) (Mullen 1983), all 14 samples define a small envelope that straddles the divider of the calc-alkaline basalt and alkaline, ocean-island basalt fields. Ten of those lie within the OIA field.

The position of the Kamloops Group samples on these diagrams supports, in part, the conclusions of Ewing (1981*b*); a component of arc character is clearly evident. For an arc, however, the Kamloops suite displays unusually high P_2O_5 and Ti/V and, in some samples, Ti, Zr, Y, and Ce/Sr. Those concentrations, along with Coombs-trend alkalinity, in which high alkali and alkaline earth contents are coupled with hypersthene- and quartz-normative mineralogy (Miyashiro 1978), indicate that subduction-related mantle hydration was not the only factor in magma generation.

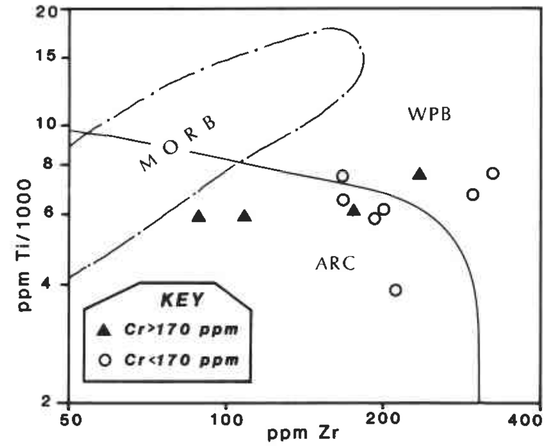

FIG. 5. Mafic Kamloops Group volcanic rocks (analyses from Ewing 1981*b*) plotted on Ti–Zr diagram (after Pearce 1982). High-Cr samples are most indicative of primary geochemistry. MORB, mid-ocean-ridge basalt; WPB, within-plate basalt.

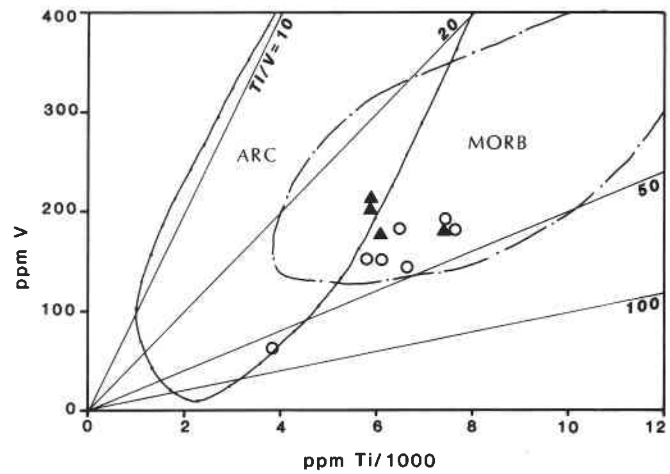

FIG. 6. Mafic Kamloops Group volcanic rocks plotted on V–Ti diagram (Shervais 1982). Symbols as for Fig. 5.

Altogether, Kamloops Group geochemistry is allied with that of "anomalous arcs," such as parts of the Lesser Antilles, New Hebrides, Aleutians, Mexico, Solomon Islands, and the Jurassic Sarmiento complex in southern Chile (Pearce 1982 and references therein). Such chemical character is suggestive of transform subduction or incipient back-arc rifting. The synvolcanic extensional regime clearly favours the latter, consistent with the findings of Church (1988) on the coeval Penticton Group. However, the principal cause of lithospheric extension in southern British Columbia may have been oblique convergence and related transcurrent and normal faulting (Price 1979; Ewing 1980; Gabrielse 1985; Price and Carmichael 1986). In that setting, Kamloops Group volcanism could have been produced by upwelling and partial fusion of upper mantle, which had previously been metasomatized by late Mesozoic and early Cenozoic subduction. The degree to which mantle currents

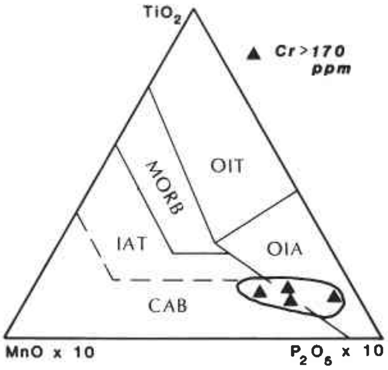

FIG. 7. Mafic Kamloops Group volcanic rocks plotted on $MnO-TiO_2-P_2O_5$ discriminant diagram (Mullen 1983). Envelope encloses 14 samples, 10 of which plot in OIA field. CAB, calc-alkaline basalt; IAT, island-arc tholeiite; MORB, mid-ocean-ridge basalt; OIA, ocean-island alkaline; OIT, ocean-island tholeiite.

played a tectonically active role (Thorkelson and Taylor 1989) is difficult to assess.

Conclusions

The Coldwater fault system is a north-northeasterly-trending Eocene structure that extends for 120 km from near Kamloops to south of Kingsvale. Vertical offsets across the system are kilometre scale. Near Kingsvale, a 15 km long north-trending portion of the fault system hosts several downdropped fault slivers, collectively called the Fig Lake Graben. Some blocks within the graben preserve Kamloops Group volcanic and sedimentary rocks. Lava flows of hornblende-needle dacite yield a K–Ar whole-rock date of 49.2 ± 1.8 Ma, coincident with the voluminous Middle Eocene magmatic pulse recorded throughout much of the Pacific northwest (Ewing 1980). Their eruption was followed by deposition in at least one of the fault blocks, of at least 2 km of conglomerate and sandstone. That succession is interpreted as having been deposited by a north-flowing braided steam, contemporaneous with extension. Relative to basement rocks to the east, that fault block is estimated as having been downdropped at least 4.5 km. Normal faulting appears to have developed in response to a component of sinistral strike-slip motion along part of the Coldwater fault system to the northeast.

Geochemical interpretation of the synextensional Kamloops Group volcanic rocks near Kamloops concurs with previous studies that describe their tectonic affinity as subduction related. An intraplate chemical signature is also evident, suggesting that Kamloops volcanism was produced by back-arc rifting or intraplate magmatism involving metasomatized mantle.

Acknowledgments

My appreciation of Eocene deformation was sparked by J. W. H. Monger during fieldwork for my M.Sc. thesis (The University of British Columbia) on the Spences Bridge Group. I am also grateful for stimulation and guidance from W. H. Mathews, G. E. Rouse, and R. L. Armstrong. Fieldwork was sponsored in 1984 by the Geological Survey of Canada and in 1985 by a Natural Sciences and Engineering Research Council of Canada (NSERC) grant to W. H. Mathews. The K–Ar determination was provided by the Department of Geological Sciences, The University of British Columbia. Other costs were borne by an NSERC grant to W. H. Mathews and by NSERC grant A1877 to R. P. Taylor. Comments by B. J. Johnson, J. M. Moore, and referees A. V. Okulitch and T. E. Ewing improved the manuscript.

BARDOUX, M. 1985. The Kelowna detachment zone, Okanagan Valley, south-central British Columbia. *In* Current research, part A. Geological Survey of Canada, Paper 85-1A, pp. 333–339.

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

CARR, S. D., PARRISH, R. R., and BROWN, R. L. 1987. Eocene structural development of the Valhalla Complex, southeastern British Columbia. Tectonics, **6**: 175–196.

CHURCH, B. N. 1975. Geology of the Hat Creek coal basin. *In* Geology in British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, pp. G99–G118.

——— 1988. Tectonomagmatic setting of the Eocene Penticton Group, south central British Columbia. Geological Society of America, Abstracts with Programs, **20**: 409.

COCKFIELD, W. E. 1948. Geology and mineral deposits of Nicola map-area, British Columbia. Geological Survey of Canada, Memoir 249.

EISBACHER, G. H. 1985. Pericollisional strike-slip faults and synorogenic basins, Canadian Cordillera. *In* Strike-slip deformation, basin formation and sedimentation. *Edited by* K. T. Biddle and N. Christie-Blick. Society of Economic Paleontologists and Mineralogists, Special Publication 37, pp. 265–282.

EWING, T. E. 1979*a*. Geology of the Kamloops Group (92 I/9, 10, 11, 15). *In* Geological fieldwork 1978. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1979-1, pp. 119–123.

——— 1979*b*. Paleogene tectonic evolution of the North American Cordillera from 40° to 56° North. Geological Society of America, Abstracts with Programs, **11**: 77.

——— 1980. Paleogene tectonic evolution of the Pacific Northwest. Journal of Geology, **88**: 619–638.

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

——— 1981*b*. Petrology and geochemistry of the Kamloops Group volcanics. British Columbia. Canadian Journal of Earth Sciences, **18**: 1478–1491.

——— 1982. Geology of the Kamloops Group near Kamloops, B.C. British Columbia Ministry of Energy, Mines and Petroleum Resources, Preliminary Map 48.

GABRIELSE, H. 1985. Major dextral transcurrent displacements along the Northern Rocky Mountain Trench and related lineaments in north-central British Columbia. Geological Society of America Bulletin, **96**: 1–14.

JOHNSON, B. J. 1988. Progress report: stratigraphy and structure of the Shuswap Metamorphic Complex in the Hunter's Range, eastern Shuswap Highland. *In* Geological fieldwork, 1987. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1988-1, pp. 55–58.

——— 1989. Geology of the west margin of the Shuswap terrane near Sicamous: implications for Tertiary extensional tectonics. *In* Geological fieldwork, 1988. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1989-1, pp. 49–54.

JOHNSON, S. Y. 1985. Eocene strike-slip faulting and nonmarine basin formation in Washington. *In* Strike-slip deformation, basin formation, and sedimentaton. *Edited by* K. T. Biddle and N. Christie-Blick. Society of Economic Paleontologists and Mineralogists, Special Publication 37, pp. 283–302.

KLEINSPEHN, K. L. 1985. Cretaceous sedimentation and tectonics, Tyaughton–Methow Basin, southwestern British Columbia. Canadian Journal of Earth Sciences, **22**: 154–174.

LONG, D. G. F. 1981. Dextral strike-slip faults in the Canadian Cordillera and depositional environments of related fresh-water intermontane coal basins. *In* Sedimentation and tectonics in alluvial basins. *Edited by* A. D. Miall. Geological Association of Canada, Special Paper 23, pp. 153–186.

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.

MCMECHAN, R. D. 1983. Geology of the Princeton Basin. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1983-3.

MIYASHIRO, A. 1978. Nature of alkalic volcanic rock series. Contributions to Mineralogy and Petrology, **66**: 91–104.

MONGER, J. W. H. 1985. Structural evolution of the southwestern Intermontane belt, Ashcroft and Hope map areas, British Columbia. *In* Current research, part A. Geological Survey of Canada, Paper 85-1A, pp. 349–358.

MONGER, J. W. H., and MCMILLAN, W. J. 1984. Bedrock geology of Ashcroft (92 I) map area. Geological Survey of Canada, Open File 980.

MULLEN, E. D. 1983. $MnO/TiO_2/P_2O_5$: a minor element discriminant for basaltic rocks of oceanic environments and its implications for petrogenesis. Earth and Planetary Science Letters, **62**: 53–62.

PARRISH, R. R., CARR, S. D., and PARKINSON, D. 1985. Metamorphic complexes and extensional tectonics, southern Shuswap complex, southeastern British Columbia. *In* Field guides to geology and mineral deposits in the southern Canadian Cordillera. Geological Society of America, pp. 12.1–12.15.

———1988. Extensional tectonics of the southern Omineca Belt, British Columbia and Washingon. Tectonics, **7**: 181–212.

PEARCE, J. A. 1982. Trace element characteristics of lavas from destructive plate boundaries. *In* Andesites. *Edited by* R. S. Thorpe. John Wiley & Sons, New York, pp. 525–548.

PRETO, V. A., OSATENKO, M. J., MCMILLAN, W. J., and ARMSTRONG, R. L. 1979. Isotopic dates and strontium isotopic ratios for plutonic and volcanic rocks in the Quesnel Trough and Nicola Belt, south-central British Columbia. Canadian Journal of Earth Sciences, **16**: 1658–1672.

PRICE, R. A. 1979. Intracontinental ductile crustal spreading linking the Fraser River and Northern Rocky Mountain Trench transform fault zones, south-central British Columbia and northeast Washington. Geological Society of America, Abstracts with Programs, **11**: 499.

———1981. Eocene stretching and necking of the crust and tectonic unroofing of the Cordilleran metamorphic infrastructure, southeastern British Columbia and adjacent Washington and Idaho. Geological Association of Canada, Program with Abstracts, **6**: A47.

PRICE, R. A., and CARMICHAEL, D. M. 1986. Geometric test for Late Cretaceous – Paleogene intracontinental transform faulting in the Canadian Cordillera. Geology, **14**: 468–471.

RICE, H. M. A. 1947. Geology and mineral deposits of Princeton map-area, British Columbia. Geological Survey of Canada, Memoir 234.

SHERVAIS, J. W. 1982. Ti–V plots and the petrogenesis of modern and ophiolitic lavas. Earth and Planetary Science Letters, **59**: 101–118.

SMITH, A. D. 1986. Isotopic and geochemical studies of terrane I, south-central British Columbia. Ph.D. thesis, The University of Alberta, Edmonton, Alta.

TAYLOR, S. B., JOHNSON, S. Y., FRASER, G. T., and ROBERTS, J. W. 1988. Sedimentation and tectonics of the lower and middle Eocene Swauk Formation in eastern Swauk Basin, central Cascades, central Washingon. Canadian Journal of Earth Sciences, **25**: 1020–1036.

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

THORKELSON, D. J. 1985. Geology of the mid-Cretaceous volcanic units near Kingsvale, southwestern British Columbia. *In* Current research, part B. Geological Survey of Canada, Paper 85-1B, pp. 333–339.

———1986. Volcanic stratigraphy and petrology of the mid-Cretaceous Spences Bridge Group near Kingsvale, southwestern British Columbia. M.Sc. thesis, The University of British Columbia, Vancouver, B.C.

THORKELSON, D. J., and ROUSE, G. E. 1989. Revised stratigraphic nomenclature and age determinations for mid-Cretaceous volcanic rocks in southwestern British Columbia. Canadian Journal of Earth Sciences, **26**. (In press.)

THORKELSON, D. J., and TAYLOR, R. P. 1989. Cordilleran slab windows. Geology. (In press.)

WILCOX, R. E., HARDING, T. P., and SEELY, D. R. 1973. Basin wrench tectonics. American Association of Petroleum Geologists Bulletin, **57**: 74–96.